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JANNE TOIKKA
PERTTI VIRTALA

Axle Load Study 2013–2014

FINAL REPORT

Janne Toikka, Pertti Virtala

Axle Load Study 2013-2014

Final report

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Finnish Transport Agency
P.O. Box 33
00521 HELSINKI
Phone 0295 34 3000

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Summary

The purpose of this work was to determine the average axle, bogey and total weights of heavy vehicles. Measurements were conducted at 16 locations in 5 different regions around Finland. The measurement points were mainly located on class I and II main roads, but there were a few additional measurement points on smaller regional roads. The measurements lasted from December 2013 to October 2014. The final data contains results for 2 372 heavy vehicles. Vehicle type specific load equivalent values were updated based on the analysed data.

The previous nationwide axle load study in Finland was conducted between the years of 1998 and 1999. Vehicles and axle configurations have changed remarkably after the previous study. In addition, the new vehicle regulation was implemented in Finland in October 2013, which increased the maximum allowed gross vehicle weights (GVW). The increase in GVWs has been believed to have an effect on the required resources for road, street, and bridge maintenance and repairing.

The axle weights of heavy vehicles were measured with a dynamic axle balance. The distance between axles was measured by using a laser sensor as a distance meter. In addition, tyre types, suspension types, loading grade and load type were registered.

The most concreate outcome of this study were the updated load equivalent values, which were determined for every vehicle group. Load equivalent vales are presented in the table below.

Load	Vehicle group			
	Trucks	Semitrailers	Full trailers	Modules
Empty	0.62	0.48	0.69	0.70
Semi full	0.70	1.02	1.60	1.01
Full	1.28	1.86	3.54	2.56
Average	0.88	1.29	2.46	1.83

Foreword

The Axle Load Study conducted by Destia Ltd. that is reported in this release was an essential part of the study programme entitled the Axle Load Programme 2013-2014 (Akselimassatutkimukset 2013-2014). BridgeWIM (Weigh-In-Motion) measurements conducted by Trafikia Ltd. from Sweden were a part of the programme as well. The steering group of the study consisted of experts from the Finnish Transport Agency as well as stakeholder group representatives from The Finnish Transport Safety Agency Trafi, The Association of Finnish Local and Regional Authorities, Finnish Forest Industries, Metsäteho Ltd., and Aalto University. The project manager of the study at the Finnish Transport Agency was Timo Tirkkonen and at Destia Ltd. the project manager was Janne Toikka.

Measurement results from axle load studies have already been utilized at the Finnish Transport Agency on clarification of design loads of bridges, amongst others. The results will still be used for the assessment of road and bridge structure durability etc. It is the aim of this study report to spread the study data to everyone who requires it, in adequate detail. A similar collective report concerning the BridgeWIM measurements is being finalized as well.

The report has been translated by Oskari Kaupinmäki, Destia Ltd.

Helsinki December 2015

Finnish Transport Agency

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1 Measurements

1.1 General

The maximum allowed heavy vehicle dimensions, as well as axle, bogie and gross vehicle weights in Finland are based on the Vehicle Regulation 1257/1992. Numerous regulations concerning masses and dimensions have been instated during the past decades. The introduction of the new vehicle regulation in October 1st of 2013 increased maximum bogie and gross vehicle weights. This has allowed the use of heavier vehicles in Finland. This change is thought to have had a profound effect on the necessity for road, street and bridge repair and maintenance. The development of maximum allowed gross vehicle weights (GVW) of heavy vehicles in Finland between the years of 1938 and 2014 is presented in Figure 1.

The purpose of this study was to determine heavy vehicles average axle, bogie, and total weights and their distributions. Vehicle type specific load equivalent values were updated based on the analysed data.

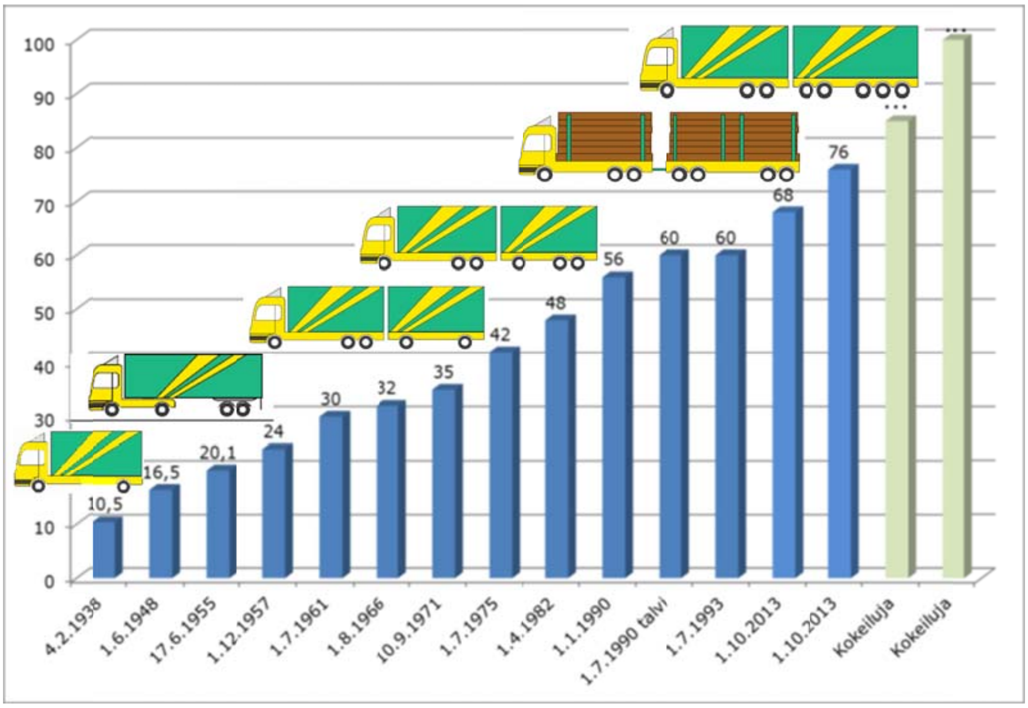


Figure 1. History of the development of maximum allowed heavy vehicle GVW in Finland between 1938 and 2013.

1.2 Measurement points and times

The measurements conducted during the axle load study have taken place after the new vehicle regulation came into effect. The first measurements were conducted in December of 2013 in the ELY centre areas of Uusimaa and Southwest Finland. During 2014 the measurements continued in the ELY centre areas of Southeast Finland, Central Finland and Northern Ostrobothnia.

In each of the measurement areas, measurements were carried out at three different daily measurement points, between the hours of 06:00 and 20:00. Measurements were conducted at an additional single measuring point at the end of the study. A total of 16 points were measured during the study.

The measurements were conducted at rest stops on the road network. Vehicles chosen for the measurements were directed to these stops from the main road. The goal was to choose the measurements points so that class I and II main roads and regional roads were all represented in the measurement programme. Each measurement point had to have a LAM-point (Automatic Traffic Measuring Point) in the vicinity so that the traffic count data contained at the measuring point could be used to extrapolate the results of the study for all traffic in the area. In addition, a measurement point from the earlier study conducted in 1998-1999 was included in this study as well.

Limiting factors in choosing the measurement points were the size of the rest stop, sight distance as well as road lighting and lighting in the rest stop. The rest area had to be large enough to accommodate the measurement equipment used in the study. An ideal rest stop had the capacity to accommodate two heavy vehicles to be measured in a single file. However, in the minor road network this was not always possible. Aerial lighting was considered very important in terms of traffic safety at the measurement points, where measurements were carried out in the autumn.

The measurement programme consisted of three separate measuring points, chosen at each measurement area, which were all located within a relatively close proximity of one another. This kept the relocating distances relatively short and allowed the dismantling and relocation of the measurement systems to be done the night before measurements commenced at a new measurement point.

Initial selection of the measurement points was done in collaboration with the Finnish Transport Agency at the office. At this time, primary measurement points were chosen from all the measurement areas with the above mentioned criteria in mind. Each measurement point was also paired with an alternate measurement point. After the initial selection, the points were inspected on site to determine whether they were suitable. Safety factors (sight distance, lighting, heavy vehicle manoeuvring such as difficulty of exiting the site on an incline) as well as factors affecting the actual measurements (smoothness of the road surface at the assumed location of the scale, space of the area) were taken into consideration during the on-site inspections. The final selection of measurement points was done on the basis of the on-site inspections.

The aim was to conduct measurements daily between the hours of 6:00 and 20:00, but due to various factors this was not always possible. The biggest factor affecting measuring times were the weather conditions that at times led to a delay in the starting time or an early finish time. There was also a single occurrence where the measurements had to be put on pause for the duration of the rush hour to prevent excessive queuing of traffic, resulting from the measuring arrangements.

The measurement areas and points are presented in the table below (Table 1).

Table 1. Locations of the measurement points

Date	Measurement point	Location	Road address	Direction	GPS-Coordinates	
Uusimaa						
10.12.2013	Point 1	Mäntsälä	4 / 111 / 1776	1 (ts. Hki -> Lahti)	60.60469	25.25678
11.12.2013	Point 2	Karhunkorpi	3 / 106 / 5700	1 (ts. Hki -> Hämeenlinna)	60.50636	24.84976
12.12.2013	Point 3	Hyvinkää	25 / 29 / 4050	1 (ts. Lohja -> Hyvinkää)	60.53326	24.68376
Date	**Measurement point**	**Location**	**Road address**	**Direction**	**GPS-Coordinates**	
Southwestern Finland						
17.12.2013	Point 4	Masku	8 / 104 / 1180	1 (ts. Turku -> Rauma)	60.53956	22.13189
18.12.2013	Point 5	Pöytyä	9 / 109 / 3215	1 (ts. Turku -> Loimaa)	60.70270	22.72438
19.12.2013	Point 6	Makarla	1 / 31 / 2250	2 (ts. Turku -> Makarla)	60.44509	22.56111
Date	**Measurement point**	**Location**	**Road address**	**Direction**	**GPS-Coordinates**	
Southeastern Finland						
20.5.2014	Point 7	Montola, länsi	6 / 215 / 1664	1 (ts. Kouvola -> Lappeenranta)	61.02883	28.07165
21.5.2014	Point 8	Montola, itä	6 / 215 / 2230	2 (ts. Lappeenranta -> Kouvola	61.03150	28.08060
22.5.2014	Point 9	Jokimies	387 / 7 / 4396	1 (ts. Lappeenranta -> Vaalimaa)	60.75636	27.98666
Date	**Measurement point**	**Location**	**Road address**	**Direction**	**GPS-Coordinates**	
Central Finland						
3.6.2014	Point 10	Tommoissuo	9 / 233 / 6645	2 (Jyväskylä -> Muurame)	62.16117	25.67927
4.6.2014	Point 11	Tiituspohja	637 / 2 / 3624	2 (ts. Laukaa -> Jyväskylä)	62.3188	25.85098
5.6.2014	Point 12	Mämmensalmi	4 / 309 / 4800	1 (ts. Jyväskylä -> Oulu)	62.64173	25.69722
Date	**Measurement point**	**Location**	**Road address**	**Direction**	**GPS-Coordinates**	
Northern Ostrobothnia						
7.10.2014	Point 13	Kiiminki	20 / 5 / 916	2 (Kiiminki -> Oulu)	65.10936	25.71750
8.10.2014	Point 14	Haukipudas	4 / 407 / 4702	1 (Oulu -> Kemi)	65.23992	25.38805
9.10.2014	Point 15	Liminka	86 / 25 / 2641	2 (ts. Liminka -> Paavola)	64.65920	25.32602
Date	**Measurement point**	**Location**	**Road address**	**Direction**	**GPS-Coordinates**	
Southeastern Finland						
30.11.2014	Point 16	Summa	7 / 32 / 3969	1 (ts. Kotka -> Hamina)	60.56848	27.07730

The locations of the measurement points are also located on a map presented in figure 2. More precise measurement area based maps are included in appendix 1.

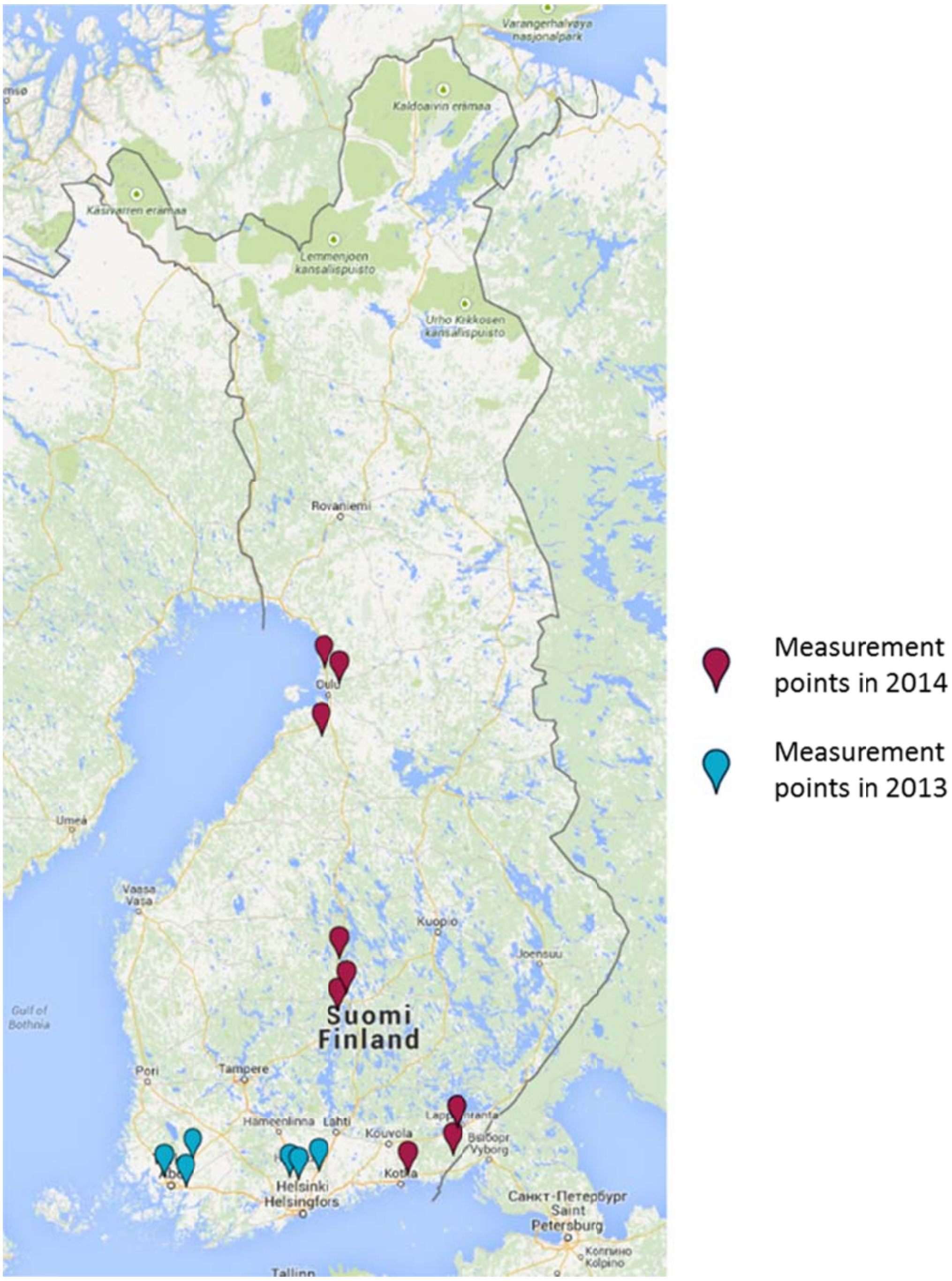


Figure 2. Map of the axle study measurement point locations.

1.3 Conducting the measurements

1.3.1 Measurement arrangements and equipment

The axle load measurements were conducted with dynamic WWSD10T scale equipment manufactured by Dini Argeon, which included two WWSD10T axle scales (figure 3) and a 3590EKR09P monitor case (figure 4). Both scale boards were connected to the monitor case by cables that came with the equipment. The monitor case in turn was connected to a measurement computer with RS232 series cables. The measurements recorded by the scale were automatically read into the measurement program in the computer through a serial port and the results were saved into the same database as the other measurement results.

Figure 3. WWSD10T scale board.

Figure 4. 3590EKR09P monitor case

Axle distances of the vehicles were measured with Noptel CM3 Distance Sensor equipment (figure 5), which was also connected to the measurement computer. Input errors were avoided by integrating the measuring equipment into a single set, which enabled automatic data transfer from the equipment to the computer.

Figure 5. Distance meter for measuring axle distances.

On-ramps were assembled on both sides of the scales for the dynamic axle load measurements (figure 6). This ensured that the vehicle being measured was at the same level with the scale for the entire duration of the measurement, and did not sway as it was being driven over the equipment. During the dynamic measurements the truck drivers were instructed to drive over the scales at a constant speed without stopping. The crossing speed during the measurement was not to exceed 10 km/h.

Figure 6. The on-ramps assembled on both sides of the axle scales.

The measurement computer and other equipment used in the study were located in the camper vehicle, which was used as an office and a social space (figure 7). Scale equipment along with the on-ramps and tools required for assembly were transported between sites in a trailer.

Figure 7. The camper as an office and a social space.

1.3.2 Traffic control

Axle load measurements were conducted on heavy vehicles, which meant that out of the traffic that was passing the measuring point, trucks, semi-trailer combination trucks, full trailer combination trucks as well as different module combinations were pulled over for measuring. Generally all heavy vehicles passing the measurement point were measured, but in instances where the measurement area was already full, the trucks were allowed to pass without being measured.

A traffic controller directed the selected heavy vehicle to the measuring point, where the driver of the vehicle was given a brochure describing the axle load study and a short verbal description of the study. Participation in the study was voluntary giving the drivers an option to decline partaking in it. The brochure that was used on site is presented in appendix 2.

Traffic control plans were made for each measurement point and were sent to each local ELY centre for approval prior to the study. Traffic arrangements and traffic control on site were done according to the plans. An example of a traffic control plan used is presented in appendix 3.

Speed displays were used in the 2014 measurements (figure 8) with the aim to enforce the effect of the traffic arrangements. According to visual observations made by the traffic controller, actual speeds at the 50 km/h zone dropped very effectively as a result of the speed displays being in place, but excessive speeders were still present. An example of average and top speeds recorded at a measurement area are represented in figure 9 below.

Figure 8. Speed display at the measuring point in Hamina.

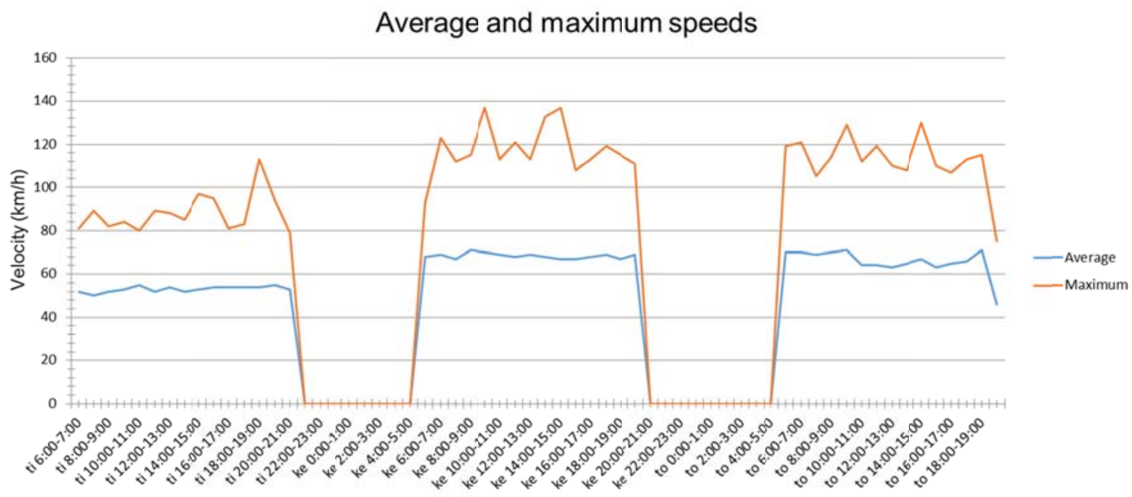


Figure 9. Measured driving speeds at the measurement points in Northern Ostrobothnia between October 7th and October 9th, 2014.

1.3.3 The measurement

The drivers participating in the study were asked a few questions about the type of cargo (soil, logs/wood, liquids, other) and loading grade (full, half-full, empty) of the vehicle. At the same time the measurement personnel inspected the type of suspension and measured the location (distances) of the axles with respect to the first axle. A photograph was taken of each vehicle partaking in the study. An example of a measurement taking place is shown in figure 10.

Figure 10. Driver interview.

Finally, the driver was instructed to drive slowly over the scale equipment without stopping. The results from the scale and the distance meter were automatically transferred to the measurement program (figure 11). This meant that the person conducting the measurements did not have to record the results manually.

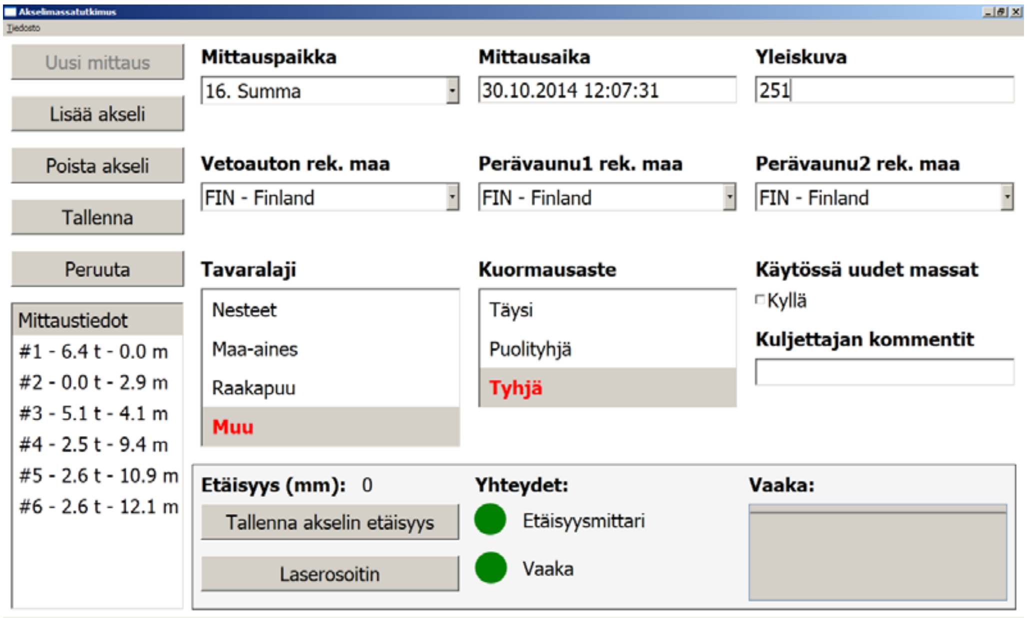


Figure 11. *The interface of the measurement program used in the measurements.*

The arrangement of the measurement equipment varied in each measurement location depending on physical constraints created by the environment. For example, at some locations axle distances were measured from the driver's side of the vehicle (figure 12) while from the right side at others. Different arrangements have no effect on the results.

Figure 12. *Axle distance measurement.*

Typically the entire measurement of a vehicle lasted about 60 seconds from the time the driver stopped at the interview point to the time when the interview was complete and the driver was free to continue. The aim of fast and efficient measurements was to prevent notable delays for heavy traffic, which could cause hauliers to avoid the measurement points. There were no observations of drivers avoiding the measurement points while measurements were being conducted, but drivers who passed the measurement points frequently during the course of a day chose different routes.

1.4 Measured quantities

The measurement results can be identified using three different variables. The variables are "measurement location", vehicle and measurement point specific "MeasurementID" and a vehicle specific "axle number." A compensation value "vehicleID" was also defined, which was used to differentiate between vehicles from different measurement points that had received the same measurementID.

An axle can belong either to the truck, to trailer1 or trailer2 (i.e. Euro combis). The axle may either be lifted or down/registered. Only axles that were down were measured (i.e. registered axles). Axles that were lifted were recorded having an axle weight of zero. The measured quantities were recorded according to table 2.

Table 2. Measured quantities.

Location	Measurement ID	Measurement time	Picture	The registration country of truck	Country code for truck	The registration country of trailer	Country code for trailer	The registration country of trailer2	Country code for trailer2	New heavier masses	Cargo type
1. Mäntsälä	6	10.12.2013	1652	Finland	FIN	Finland	FIN			EPÄTOSI	Raaka-ainekuljetukset
1. Mäntsälä	6	10.12.2013	1652	Finland	FIN	Finland	FIN			EPÄTOSI	Raaka-ainekuljetukset
1. Mäntsälä	6	10.12.2013	1652	Finland	FIN	Finland	FIN			EPÄTOSI	Raaka-ainekuljetukset
1. Mäntsälä	7	10.12.2013	1653	Finland	FIN	Finland	FIN			EPÄTOSI	Raaka-ainekuljetukset
1. Mäntsälä	7	10.12.2013	1653	Finland	FIN	Finland	FIN			EPÄTOSI	Raaka-ainekuljetukset
1. Mäntsälä	7	10.12.2013	1653	Finland	FIN	Finland	FIN			EPÄTOSI	Raaka-ainekuljetukset
1. Mäntsälä	7	10.12.2013	1653	Finland	FIN	Finland	FIN			EPÄTOSI	Raaka-ainekuljetukset

Load	Driver's comments	Axel number	Axel distance	Truck or trailer	Axel position	Suspension type	Tyre type	Measured weight
Tyhjä		1	0	1_Vetoauto	Alhaalla	Muu	Yksittäinen pyörä	4810
Tyhjä		2	6200	1_Vetoauto	Alhaalla	Ilmajousi	Paripyörä	9570
Tyhjä		3	7592	1_Vetoauto	Ylhäällä	Ilmajousi	Yksittäinen pyörä	0
Tyhjä		1	0	1_Vetoauto	Alhaalla	Ilmajousi	Yksittäinen pyörä	5180
Tyhjä		2	3953	1_Vetoauto	Alhaalla	Ilmajousi	Paripyörä	5550
Tyhjä		3	5339	1_Vetoauto	Alhaalla	Ilmajousi	Paripyörä	4760
Tyhjä		4	6628	1_Vetoauto	Ylhäällä	Ilmajousi	Yksittäinen pyörä	0

EPÄTOSI = untrue *Raaka-ainekuljetukset = raw material transports*
Tyhjä = empty *Vetoauto = truck* *Alhaalla = down* *Ylhäällä = up* *Muu = other*
Ilmajousi = air suspension *Yksittäinen pyörä = single tyre* *Pari pyörä = twin tyre*

1.5 Calculated quantities

Compensation factors were needed for the analysis of the measurement results, which were determined separately using specific computing rules. Rules were required for bogie construction with which it was determined how many axles belonged to the same bogie. The bogie groups were determined according to axle distances defined in the vehicle regulation. At the same time maximum allowed weights for bogies and their axles were defined. Based on that, the axles were classified as either overweight or within allowable limits, with an overweight code 0/1. The calculated compensation factors are displayed in the table below (table 3).

Table 3. Calculated compensation factors.

Front axl	Axle distan	Bogey numb	Allowable load 19X	Allowable load 20:	Driving ax	Truck ty	Over weig
1		1	0	10	Ei vetävä	1	0
0	6200	1	0	11,5	Vetävä	1	0
0	1392	1	0	10	Ei vetävä	1	0
1		1	0	10	Ei vetävä	1	0
0	3953	2	0	9	Ei vetävä	1	0
0	1386	2	0	9	Vetävä	1	0
0	1289	1	0	10	Ei vetävä	1	0

Vetävä / Ei vetävä = is a drive axle / is not a drive axle

Vehicles were classified into four vehicle categories, which were trucks without trailers (KAIP), semi-trailer combination trucks (KAPP), full trailer combination trucks (KAVP/KATP), and module combinations. In the table the name of this group is VehicleType and it is either given a value of 1, 2, 3, or 4.

1.6 Classification criteria

Results of the study were classified into vehicle groups and vehicle types. Vehicle groups were as follows:

- Trucks without trailers (KAIP)
- Semi-trailer combination truck (KAPP)
- Full trailer combination trucks (KAVP1)
- Module combinations (KAVP2)

Full trailer combination trucks consisted of a truck and one trailer, which contained two axle/bogie groups. Module combinations consisted of a truck with two trailers of which the first trailer was a semi-trailer or a full trailer type.

Vehicle axles were classified into bogie configurations, which were based on the number of axles per bogie (1 – 6 axle bogies). An axle was classified as belonging to the same bogie if the axle distance was a maximum of 2.6 m. Vehicle type was based on the structural axle amount of all registered axles. Axles that were raised were not taken into consideration when calculating average weights.

Vehicles were classified based on vehicle types, vehicle groups and bogie configurations. Trucks were divided into five types (figure 13), semi-trailers into four types (figure 14) and trailers (figure 15) into six different types. The different truck and trailer combinations of modules also formed additional types. The most common secondary trailers of module combinations are presented in figure 16.

Type	Picture
1	
2	
3	
4	
5	

Figure 13. KAIP vehicle group types.

Type	Picture
1	
2	
3	
4	

Figure 14. KAPP vehicle group's trailer types.

Type	Picture
11	
12	
13	
22	
23	
35	

Figure 15. *KAVP vehicle group's trailer types.*

Type	Picture
2	
3	

Figure 16. *KAVP2 vehicle group's trailer types.*

In addition to vehicle group classification a COST code was given for each vehicle. The COST codes for heavy vehicles have been prepared in an OECD COST workgroup prior to this study.

2 Results

2.1 Vehicle volumes

A total amount of 2 372 heavy vehicles participated in the study and their distribution into the vehicle groups (KAIP, KAPP, KAVP1/KAVP2) is shown in the following table (table 4). There were 531 trucks without trailers (KAIP), 661 semi-trailer combination trucks (KAPP), 1 089 full trailer combination trucks (KAVP1), and 61 module combinations (KAVP2). The percentage of trucks without trailers (KAIP) varied by site from 3 % to 58 %, the percentage of semi-trailers (KAPP) varied from 3 % to 66 %, and the percentage of full trailers and module combinations (KAVP1/KAVP2) varied from 16 % to 56 %. The number of vehicles and vehicle groups by site are presented in figures 17 and 18.

Table 4. Vehicle percentages per group (amount and %) at different measurement sites.

Location	KAIP 1	KAPP 2	KAVP1 3	KAVP2 4	Total	KAIP 1	KAPP 2	KAVP1 3	KAVP2 4	Total
1. Mäntsälä	18	34	42		94	19,1 %	36,2 %	44,7 %		4,0 %
2. Karhunkorpi	13	58	44	1	116	11,2 %	50,0 %	37,9 %		4,9 %
3. Hyvinkää	29	58	60		147	19,7 %	39,5 %	40,8 %		6,2 %
4. Masku	59	54	58		171	34,5 %	31,6 %	33,9 %		7,2 %
5. Pöytyä	32	18	47	1	98	32,7 %	18,4 %	48,0 %		4,1 %
6. Makarla	25	74	65		164	15,2 %	45,1 %	39,6 %		6,9 %
7. Montola, länsi	5	70	81	3	159	3,1 %	44,0 %	50,9 %		6,7 %
8. Montola, itä	17	79	132	11	239	7,1 %	33,1 %	55,2 %	4,6 %	10,1 %
9. Jokimies	9	34	8		51	17,6 %	66,7 %	15,7 %		2,2 %
10. Tommoissuo	66	34	128	6	234	28,2 %	14,5 %	54,7 %	2,6 %	9,9 %
11. Tiituspohja	105	6	66	3	180	58,3 %	3,3 %	36,7 %	1,7 %	7,6 %
12. Mämmensalmi	32	39	108	10	189	16,9 %	20,6 %	57,1 %	5,3 %	8,0 %
13. Kiiminki	42	6	50	2	100	42,0 %	6,0 %	50,0 %	2,0 %	4,2 %
14. Haukipudas	27	40	102	13	182	14,8 %	22,0 %	56,0 %	7,1 %	7,7 %
15. Liminka	18	4	28	4	54	33,3 %	7,4 %	51,9 %	7,4 %	2,3 %
16. Summa	34	83	70	7	194	17,5 %	42,8 %	36,1 %	3,6 %	8,2 %
All	**531**	**691**	**1089**	**61**	**2372**	**22,4 %**	**29,1 %**	**45,9 %**	**2,6 %**	100 %

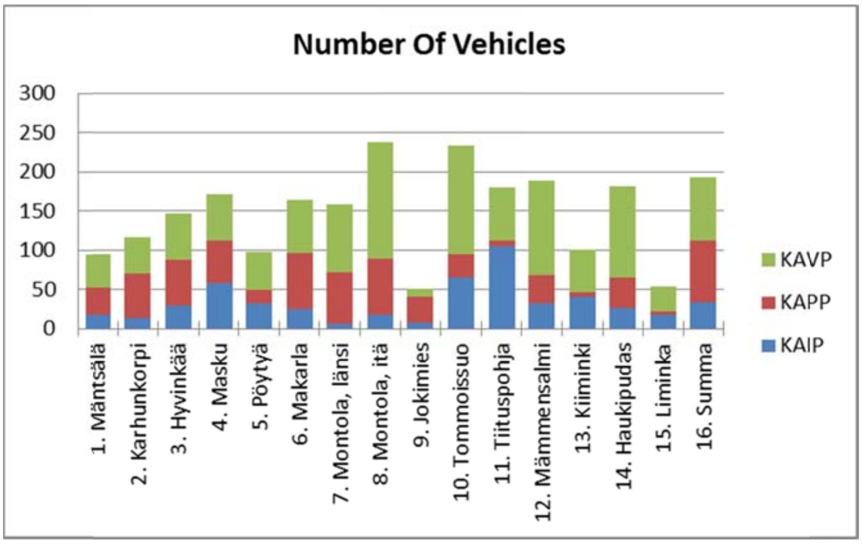


Figure 17. Vehicle volumes per measurement site.

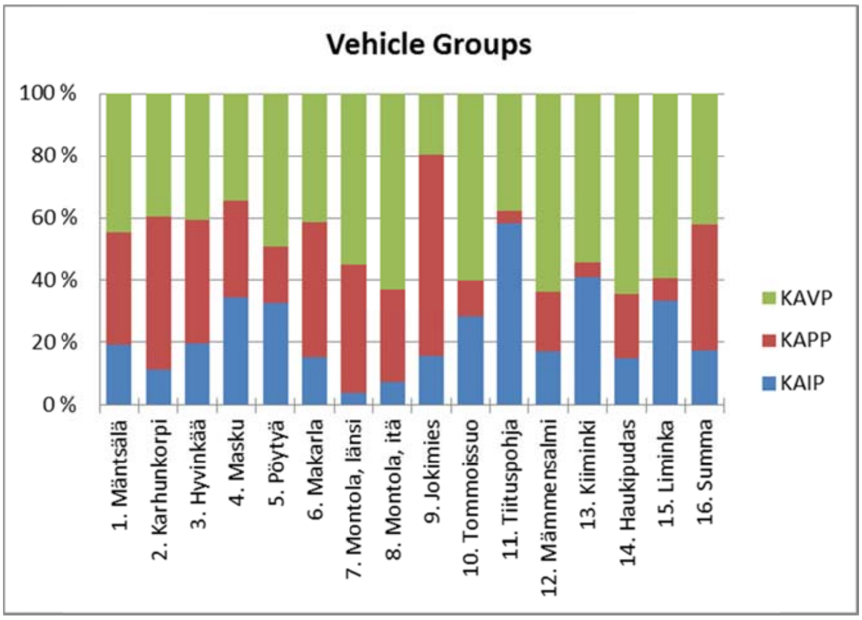


Figure 18. Vehicle group percentage per measurement site.

The count and the percentages of different vehicle groups and vehicle types are presented in tables 5 and 6. After data validation, the distributions per vehicle group in the study were as follows: KAIP 22.8 %, KAPP 31.5 %, KAVP 43 %. The KAPP and KAVP groups contain module combinations, which comprised a 2.7 % percentage of all vehicles in the study.

Table 5. The amount of vehicles per truck and trailer type.

Group	Trailer Type		Truck Type					Total	
			1	2	3	4	5		
			O O	O OO	O OOO	O O OO	O O OOO	amount	%
KAIP	0	-	231	247	44	14	5	541	22,8 %
KAPP	1	O	2	1		3		6	31,5 %
	2	OO	5	52	2			59	
	3	OOO	344	336	2			682	
	4	OOOO		1				1	
KAVP1	11	O O	2	5				7	43,0 %
	12	O OO	9	31	57	6	2	105	
	13	O OOO	5	14		1		20	
	22	OO OO		437	46	6	5	494	
	23	OO OOO	5	403	45	2		455	
	31	OOO O		1				1	
	35	OOO OOOOO		1				1	
KAVP2	1	O		1				1	2,7 %
	2	OO	2	15				17	
	3	OOO	1	41	3			45	
All			603	1529	196	32	12	2372	100 %

The KAIP group mainly consisted of two and three axle vehicle types 1 and 2, which amounted to a total percentage of 88.4 %. Four and five axle vehicles had a portion of only a few percent. In the KAPP group 2 and 3 axle trucks were most common with a type 3, three axle trailer. Other groups only comprised very minor percentages. Out of actual module combinations, the KAVP1 group mostly comprised of type 2 three axle trucks with either a four axle 2+2 or a five axle 2+3 trailer. The percentage of these combinations was 77.6 %. The most common second trailer in module combinations was a three axle trailer with a 65.1 % percentage out of all the module combinations.

Table 6. The percentage of vehicles per truck and trailer type

Group	Trailer Type		Truck Type 1	Truck Type 2	Truck Type 3	Truck Type 4	Truck Type 5	Total	
			O O	O OO	O OOO	O O OO	O O OOO	%	%
KAIP	0	-	42,7 %	45,7 %	8,1 %	2,6 %	0,9 %	100 %	22,8 %
KAPP	1	o	0,3 %	0,1 %		0,4 %		100 %	31,5 %
	2	oo	0,7 %	7,0 %	0,3 %				
	3	ooo	46,0 %	44,9 %	0,3 %				
	4	oooo		0,1 %					
KAVP1	11	o o	0,2 %	0,5 %				100 %	43,0 %
	12	o oo	0,8 %	2,9 %	5,3 %	0,6 %	0,2 %		
	13	o ooo	0,5 %	1,3 %		0,1 %			
	22	oo oo		40,4 %	4,2 %	0,6 %	0,5 %		
	23	oo ooo	0,5 %	37,2 %	4,2 %	0,2 %			
	31	ooo o		0,1 %					
	35	ooo ooooo		0,1 %					
KAVP2	1	o		1,6 %				100 %	2,7 %
	2	oo	3,2 %	23,8 %					
	3	ooo	1,6 %	65,1 %	4,8 %				
All			0,1 %	0,6 %	0,0 %	0,0 %	0,7 %	100 %	100 %

The percentages of different vehicles in this study and the study conducted in 1998-1999 are presented in table 7. To ease comparability between the two studies, a group in the previous study consisting of buses has been removed from the table. The table shows that the percentage of semi-trailers has increased since the previous study while the percentage of trailers has decreased by a little over 10 %. Module combinations comprise a completely new group in the new study, but their percentage is small for the time being.

Table 7. Vehicle group percentages in the axle load study of 1999 and 2013.

Type	Picture	Study 1998-99		Study 2013-2014	
		Amount	Fraction	Amount	Fraction
KAIP		829	25.0 %	541	22.8 %
KAPP		623	18.8 %	748	31.5 %
KAVP		1863	56.2 %	1083	45.7 %
MODULE		-	-	63	2.7 %

2.2 The number of axles

A total of 13 832 axles were examined in the study and they have been cross tabulated in the following tables (tables 8–10) according to different background factors. Axle amounts per trucks and the amount of axles per bogie in trucks and trailers are represented separately in table 8.

Table 8. The amount of axles per combination, trucks and bogie groups.

Combination / Bogie	Truck Type					Total
	1	2	3	4	5	
1_Truck	**1209**	**4592**	**784**	**128**	**60**	**6773**
1 axel	1209	1534	196	64	19	3022
2 axel bogie		3058		64		3122
3 axel bogie			588		21	609
4 axel bogie					20	20
2_Trailer1	**1121**	**5097**	**588**	**59**	**26**	**6891**
1 axel	21	57	58	10	2	148
2 axel bogie	38	2724	392	40	24	3218
3 axel bogie	1062	2265	138	9		3474
4 axel bogie		40				40
5 axel bogie		5				5
6 axel bogie		6				6
3_Trailer2	**7**	**152**	**9**	**0**	**0**	**168**
1 axel		1				1
2 axel bogie	4	28				32
3 axel bogie	3	123	9			135
All	**2571**	**9549**	**873**	**757**	**82**	**13832**

Table 9. The amount of axles per combination, tyre types and bogie groups.

Combination / Bogie	Tyres			
	Double	Supersingle	Single	Total
1_Truck	**3178**	**400**	**3164**	**6742**
1 axel	627	11	2415	3053
2 axel bogie	2158	313	589	3060
3 axel bogie	382	72	155	609
4 axel bogie	11	4	5	20
2_Trailer1	**1826**	**2994**	**2106**	**6926**
1 axel	127	34	22	183
2 axel bogie	1346	1185	693	3224
3 axel bogie	313	1767	1388	3468
4 axel bogie	29	8	3	40
5 axel bogie	5			5
6 axel bogie	6			6
3_Trailer2	**21**	**92**	**51**	**164**
1 axel			1	1
2 axel bogie	6	22		28
3 axel bogie	15	70	50	135
All	**5025**	**3486**	**5321**	**13832**

Table 10. The amount of axles per bogie, suspension and tyre types.

Suspension / Bogie	Tyres			
	Double	Supersingle	Single	Total
airsuspension	**3323**	**3065**	**3792**	**10180**
1 axel	604	31	1119	1754
2 axel bogie	2305	1290	1170	4765
3 axel bogie	405	1740	1502	3647
4 axel bogie	9	4	1	14
other	**1702**	**421**	**1529**	**3652**
1 axel	150	14	1319	1483
2 axel bogie	1205	230	112	1547
3 axel bogie	305	169	91	565
4 axel bogie	31	8	7	46
5 axel bogie	5			5
6 axel bogie	6			6
All	**5025**	**3486**	**5321**	**13832**

2.3 Gross vehicle weights

2.3.1 At different measurement areas

GVW varied between 5 000 and 110 000 kg. GVW distributions followed similar patterns at different measurement locations and on different dates (figures 19–21). The maximum GVWs appear to increase slightly where measurements were conducted later in the year. Measured oversized transport masses are included in all the averages mentioned below.

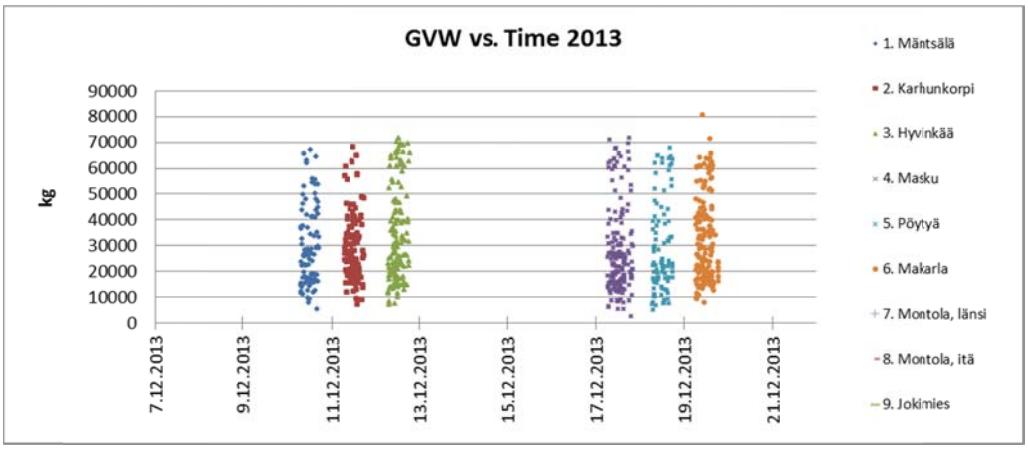


Figure 19. *GVW per measurement location and date during the 2013 measurements.*

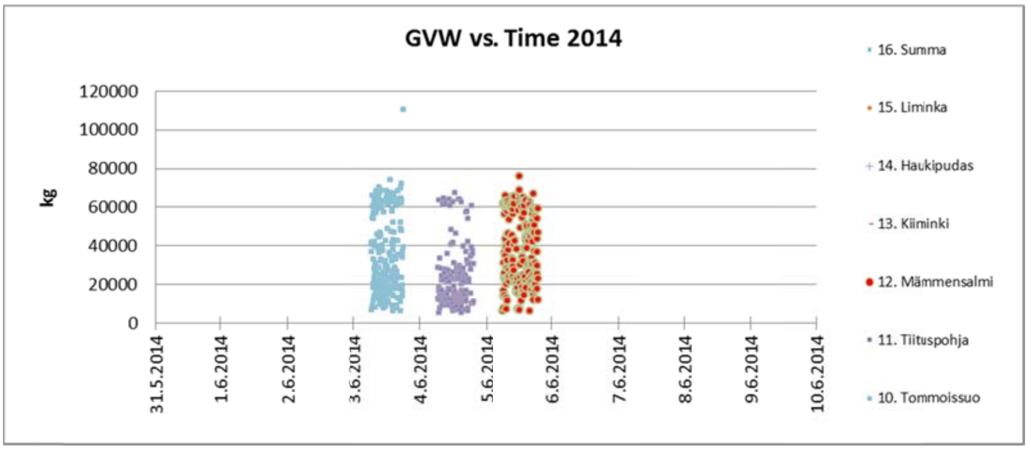


Figure 20. *GVW per measurement location and date during the 2014 measurements.*

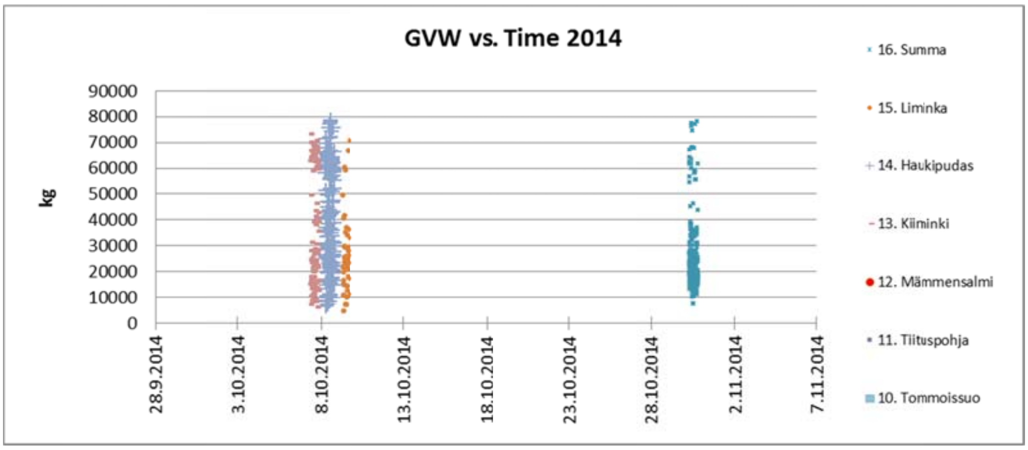


Figure 21. *GVW per measurement location and date during the 2014 measurements.*

2.3.2 By cargo type

The vehicle groups are distributed by cargo type according to table 11. The most common vehicle for all cargo types was a trailer (KAVP1) with a percentage of all transports varying between 40 % and 86 %. Semi-trailers constituted a third of all transports with a percentage varying between 3 % and 33 %, which came up to a third in the liquid, raw material, and other cargo groups.

Table 11. Vehicles groups by cargo types and their percentage.

Goods	Truck Type				Total	Truck Type				Total
	KAIP	KAPP	KAVP1	KAVP2		KAIP	KAPP	KAVP1	KAVP2	
Earth	19	2	48		69	27,5 %	2,9 %	69,6 %	0,0 %	100 %
Other	468	604	744	53	1869	25,0 %	32,3 %	39,8 %	2,8 %	100 %
Fluids	20	27	114	6	167	12,0 %	16,2 %	68,3 %	3,6 %	100 %
Fluid transportation	5	15	25		45	11,1 %	33,3 %	55,6 %	0,0 %	100 %
Raw materials	17	30	56	1	104	16,3 %	28,8 %	53,8 %	1,0 %	100 %
Raw wood	2	13	102	1	118	1,7 %	11,0 %	86,4 %	0,8 %	100 %
All	**531**	**691**	**1089**	**61**	**2372**	22,4 %	29,1 %	45,9 %	2,6 %	100 %

2.3.3 GVW distributions

The average GVW of all vehicles was 32.8 tons. GVWs varied between 2.4 and 80 tons. An exceptional vehicle (oversized vehicle) with a GVW of 110.2 tons was also measured. GVW distribution is presented in figure 22.

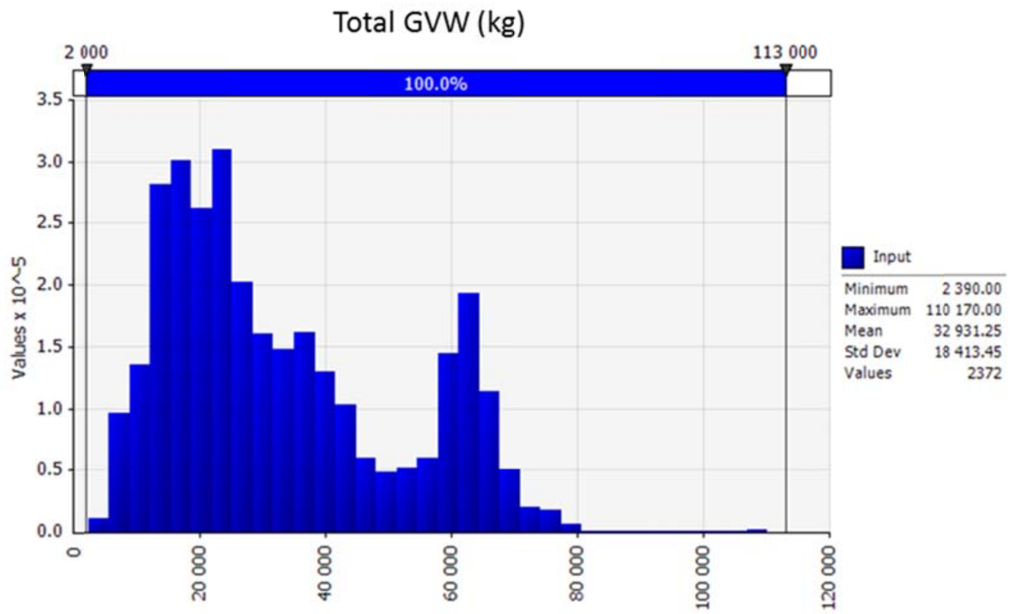


Figure 22. GVW distribution of vehicles at all locations.

The average GVW of trucks and trailers was 17.9 and 18.6 tons respectively. The respective maximum weights were 41 and 76.5 tons. GVW distributions are presented in figures 23 and 24.

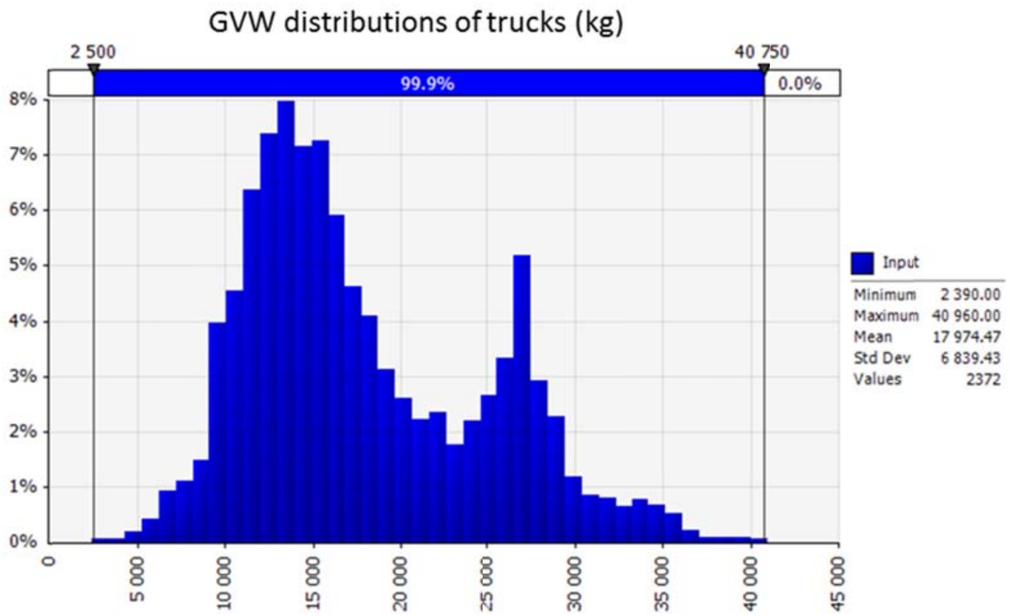


Figure 23. GVW distributions of trucks.

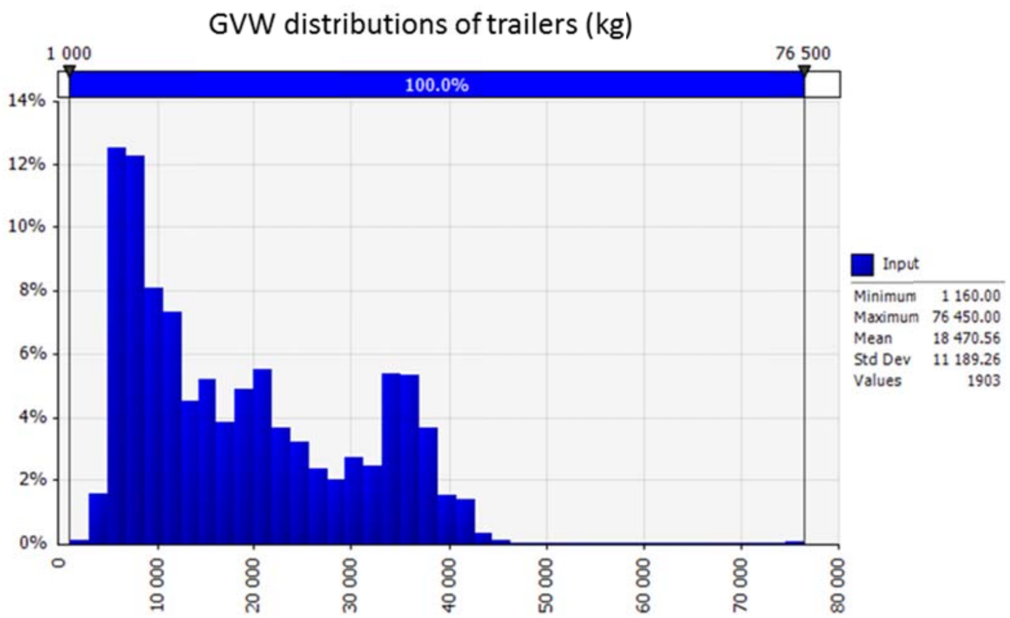


Figure 24. GVW distribution of trailers.

2.3.4 GVW distributions in vehicle groups

The average GVW in the KAIP group was 15.1 tons and it varied between 2.4 and 41.0 tons.

The average GVW in the KAPP group was 27.4 tons and it varied between 9.2 and 60 tons. An exceptional vehicle (oversized vehicle) with a GVW of 80.6 tons was also measured.

The average GVW in the KAVP1 group was 43.8 tons and it varied between 14.5 and 80 tons. An exceptional vehicle (oversized vehicle) with a GVW of 110 tons was also measured.

The average GVW of module combinations was 43.9 tons and they varied between 22.3 and 79 tons.

The GVW distributions by vehicle groups are presented in figures 25–28.

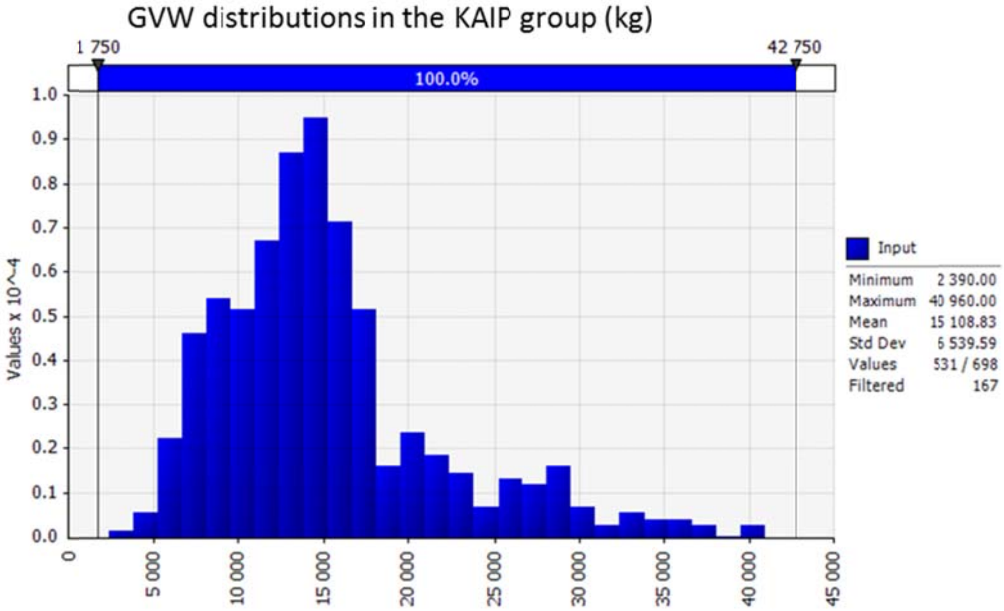


Figure 25. GVW distribution in the KAIP group (kg).

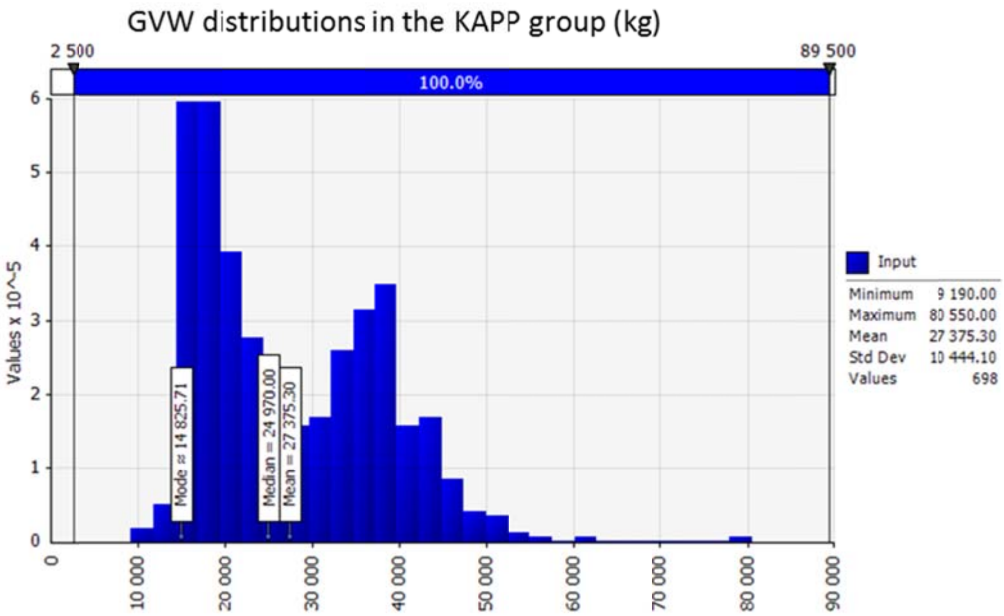


Figure 26. GVW distribution in the KAPP group (kg).

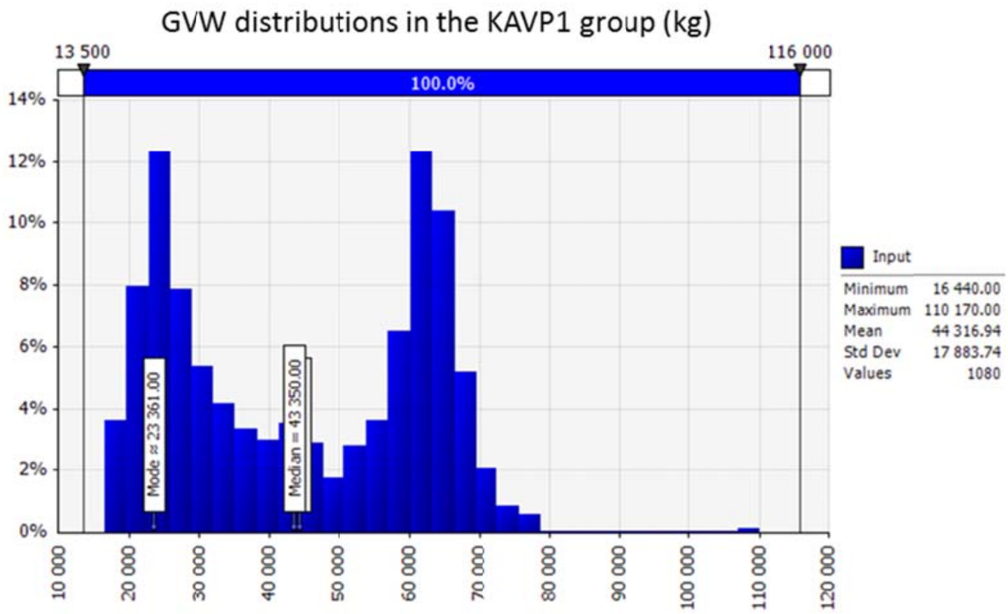


Figure 27. GVW distribution in the KAVP1 group (kg).

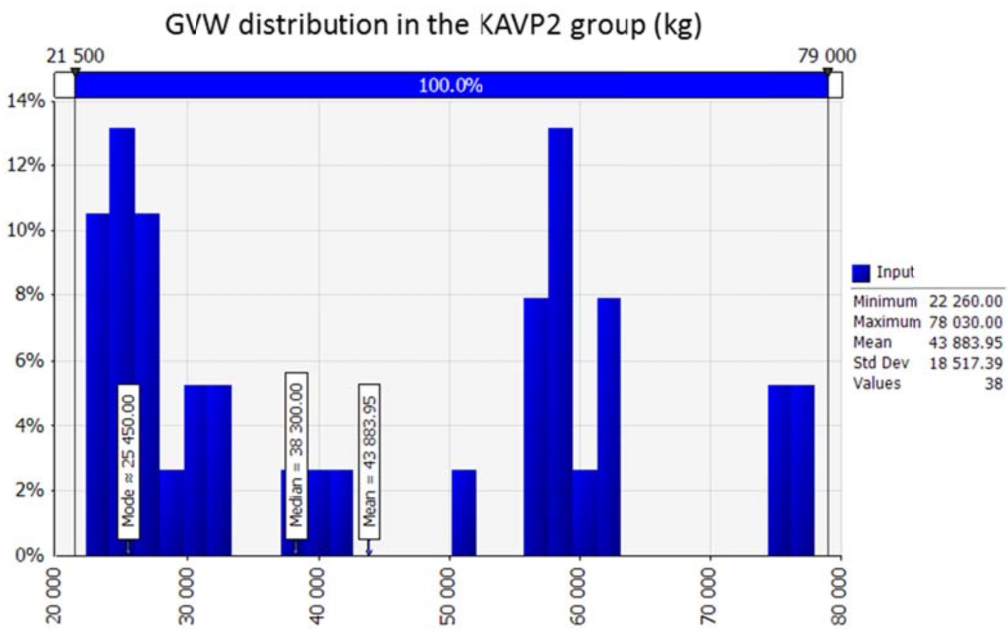


Figure 28. GVW distribution in the KAVP2 group (kg).

2.3.5 GVW in relation to loading grade

A rough record of loading grades was recorded in accordance to three levels of classification: full, half full, and empty (table 12). The highest amount of full loads was observed in module combinations in the KAVP2 group (63%) and the second most were in trailers in the KAVP1 group (58 %). The least amount of full loads was in the KAIP group.

The percentage of fully loaded vehicles was 52 % and 32 % for empties. The GVW distributions of full and empty vehicles are presented in figures 29-34.

Table 12. The amount of vehicles and their percentages according to the loading grade.

Load	Truck Type				Total
	KAIP	KAPP	KAVP1	KAVP2	
Half full	143	111	134	9	397
Empty	199	218	318	16	751
Full	189	362	637	36	1224
All	531	691	1089	61	2372

Load	Truck Type				Total
	KAIP	KAPP	KAVP1	KAVP2	
Half full	27 %	16 %	12 %	15 %	17 %
Emtpy	37 %	32 %	29 %	26 %	32 %
Full	36 %	52 %	58 %	59 %	52 %
All	100 %	100 %	100 %	100 %	100 %

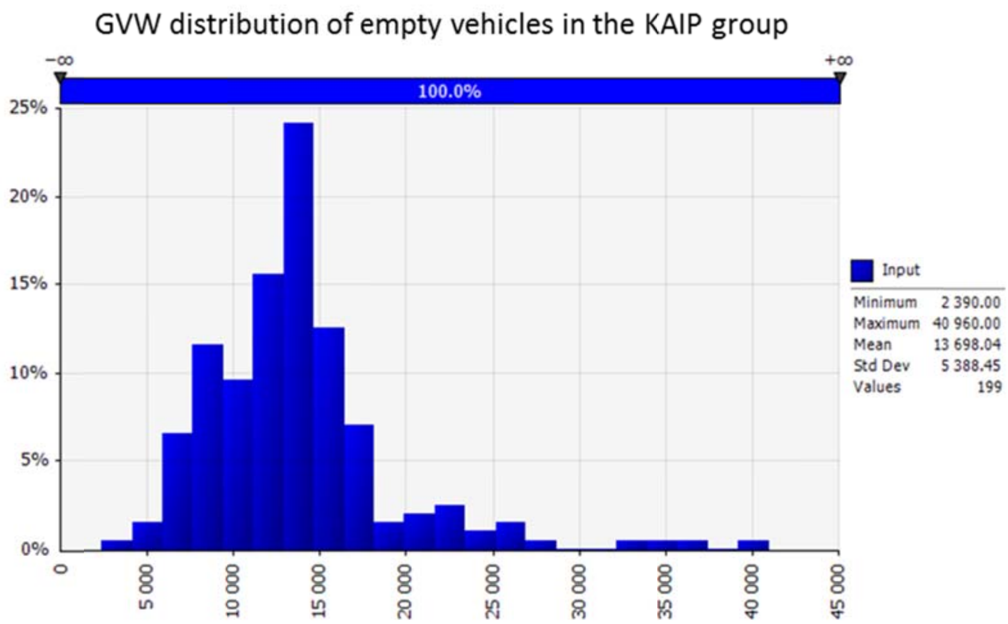


Figure 29. GVW distribution of empty vehicles in the KAIP group.

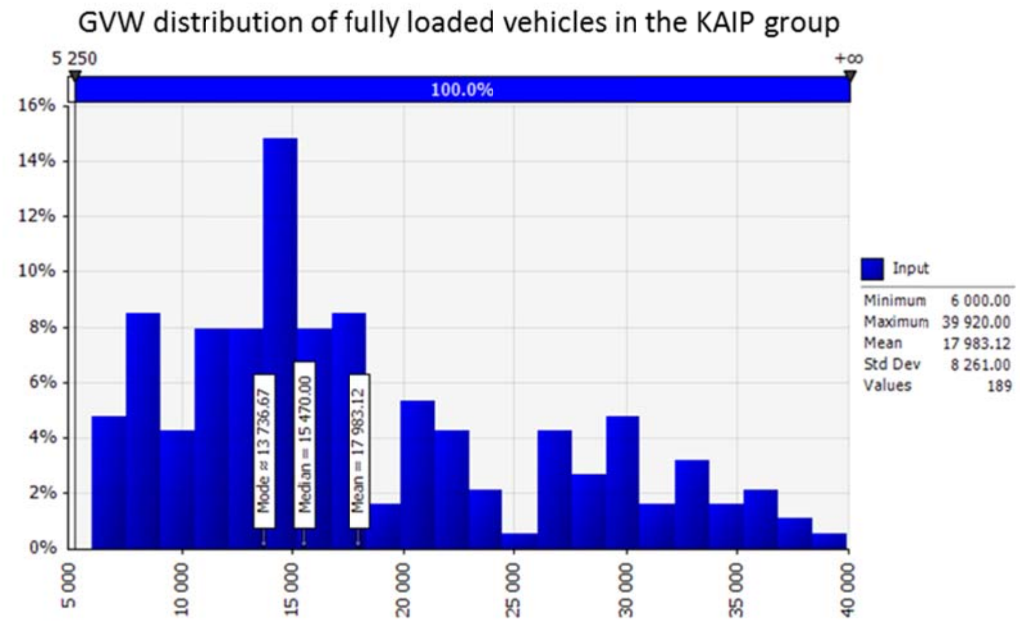


Figure 30. GVW distribution of fully loaded vehicles in the KAIP group.

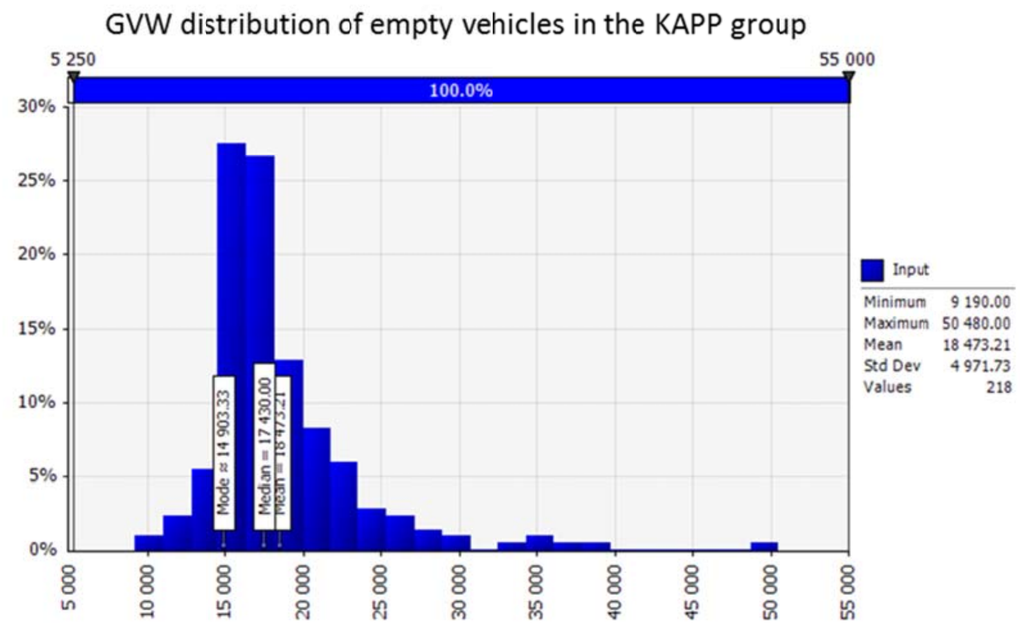


Figure 31. GVW distribution of empty vehicles in the KAPP group.

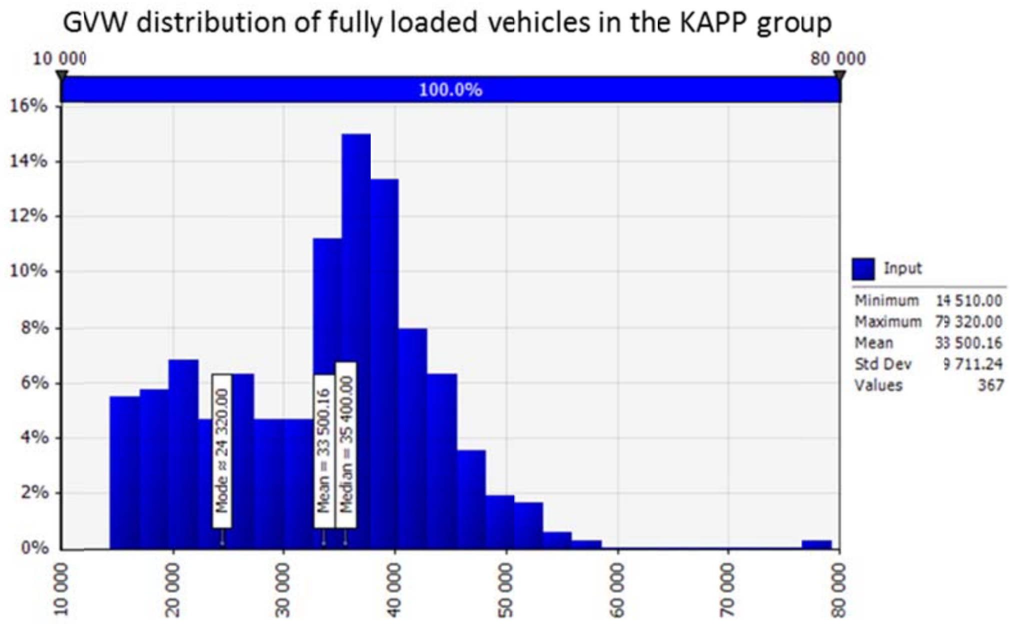


Figure 32. GVW distribution of fully loaded vehicles in the KAPP group.

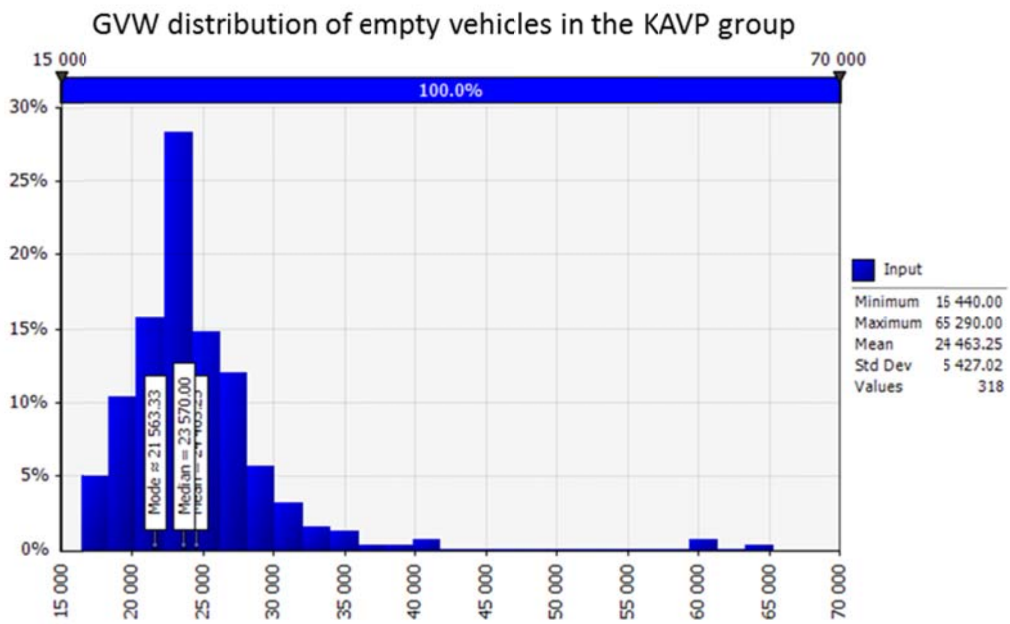


Figure 33. GVW distribution of empty vehicles in the KAVP group.

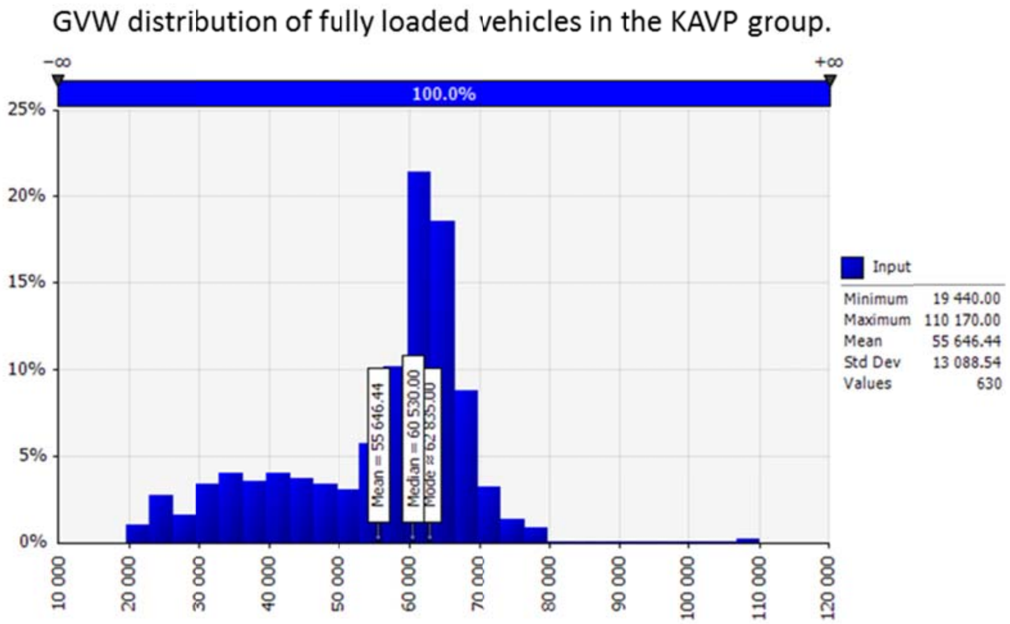


Figure 34. GVW distribution of fully loaded vehicles in the KAVP group.

2.4 Axle loads

2.4.1 Averages by background variables

The average axle load of vehicles was 5 624 kg. The average axle loads according to different background factors have been cross tabulated in the tables below (tables 13–15).

With twin tyres the average axle load was 6.9 tons, 4.6 tons with super single tyres and 5.1 tons with individual singles. The average axle weight varied between 2.0 and 6.9 tons depending on the measurement location.

Table 13. Average axle loads by measurement location and tyre configuration (kg).

Location	Double	Supersingle	Single	Average
1. Mäntsälä				
1_Truck	7119		5118	6026
2_Trailer1	4289	4778	3917	4221
2. Karhunkorpi				
1_Truck	7050	1930	5178	5917
2_Trailer1	5655	3896	3828	4100
3_Trailer2			1973	1973
3. Hyvinkää				
1_Truck	7996		5406	6657
2_Trailer1	6957	4120	4771	5296
4. Masku				
1_Truck	7075	0	5149	6053
2_Trailer1	6175	3722	4135	4699
5. Pöytyä				
1_Truck	7128		5265	6162
2_Trailer1	5955	3288	4372	4613
3_Trailer2			6033	6033
6. Makarla				
1_Truck	7786		5606	6580
2_Trailer1	6290	4034	4676	4832
7. Montola, länsi				
1_Truck	7594	4238	5606	6469
2_Trailer1	6276	5002	4590	5258
3_Trailer2	2550	6132		5109
8. Montola, itä				
1_Truck	7746	4456	6149	6704
2_Trailer1	6679	5240	4533	5641
3_Trailer2	7386	6087		6598
9. Jokimies				
1_Truck	7225	4366	5624	6349
2_Trailer1	3141	5103	5500	4514
10. Tommoissuo				
1_Truck	7583	4067	6143	6519
2_Trailer1	6237	5078	5830	5457
3_Trailer2		2339		2339
11. Tiituspohja				
1_Truck	6463	2416	5045	5345
2_Trailer1	4267	4131	6396	4229
3_Trailer2	1950	2085		2070
12. Mämmensalmi				
1_Truck	7583	4056	6067	6557
2_Trailer1	4846	5187	5533	5102
3_Trailer2		5223		5223
13. Kiiminki				
1_Truck	7724	2450	5806	6671
2_Trailer1	7540	6328	4665	6111
3_Trailer2		2260		2260
14. Haukipudas				
1_Truck	7780	4920	6030	6889
2_Trailer1	7020	4421	5589	5775
3_Trailer2	7968	4091	5008	5205
15. Liminka				
1_Truck	6115		4693	5328
2_Trailer1	4747	3377	3161	3556
3_Trailer2			2237	2237
16. Summa				
1_Truck	6513	1795	5175	5630
2_Trailer1	4659	3515	3934	3940
3_Trailer2	2345	7485	3165	4811
Total Average	6854	4616	5123	5624

The average axle loads by tyre and suspension combinations as well as by axle amounts are presented in tables 14 and 15. There were only a very few axle combinations having 5–6 axles per bogie. The highest average in axle loads was in axles equipped with twin tyres and the smallest in axles equipped with super single tyres.

Table 14. Average axle loads according to loading grade, suspension type and tyre configuration.

Load / Suspension	Tyres			
	Double	Supersingle	Single	Average
Half empty	**6472**	**3958**	**4602**	**5045**
Airsuspension	6552	3994	4215	4871
Other	6227	3730	5788	5659
Empty	**4276**	**2077**	**3551**	**3462**
Airsuspension	4523	2110	2934	3214
Other	3873	1889	4843	4034
Full	**8394**	**6086**	**6255**	**7007**
Airsuspension	8288	5997	6043	6772
Other	8602	6871	6799	7698
Total Average	**6854**	**4616**	**5123**	**5624**

Table 15. Average axle loads according to different tire and suspension as well as bogie configurations.

Suspension / Bogie	Tyres			
	Double	Supersingle	Single	Average
Airsuspension	**6925**	**4623**	**4785**	**5435**
1 axel	6862	5326	6233	6434
2 axel bogie	7002	4666	4372	5724
3 axel bogie	6664	4586	4026	4586
4 axel bogie	3193	1835	5330	2958
Other	**6714**	**4563**	**5962**	**6152**
1 axel	6397	6625	6271	6287
2 axel bogie	6951	4757	4131	6421
3 axel bogie	6119	4121	3598	5115
4 axel bogie	4581	4695	7821	5094
5 axel bogie	10644			10644
6 axel bogie	5145			5145
Total Average	**6854**	**4616**	**5123**	**5624**

2.4.2 The distribution by vehicle groups

Axle load distributions have been reviewed in figures 35-41. Axle load distributions are more consistent than GVW distributions. Generally there is only one peak in the distributions, but occasionally there are two. Axles that have been raised have not been taken into consideration in axle load reviews. Axle load distributions with lifted axles in the KAIP group are presented in figure 35 and distributions where the lifted axles have been left out are presented in figure 36. Lifted axles have been removed from all latter figures.

The average axle load in the KAIP group was 6.9 tons and it varied between 0.7 and 14.9 tons.

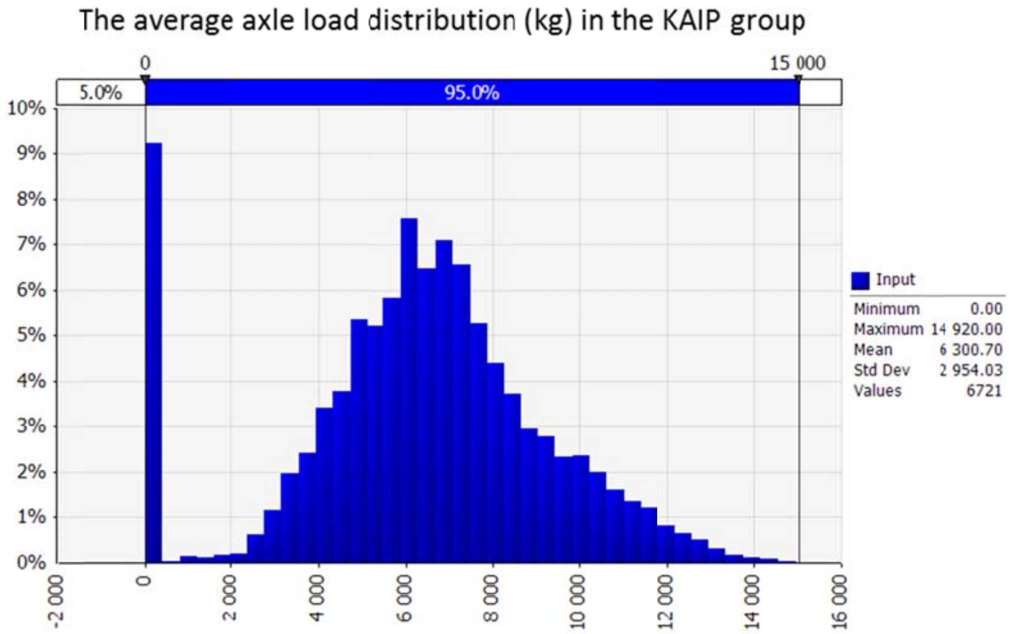


Figure 35. *The average axle load distribution (kg) in the KAIP group including lifted axles.*

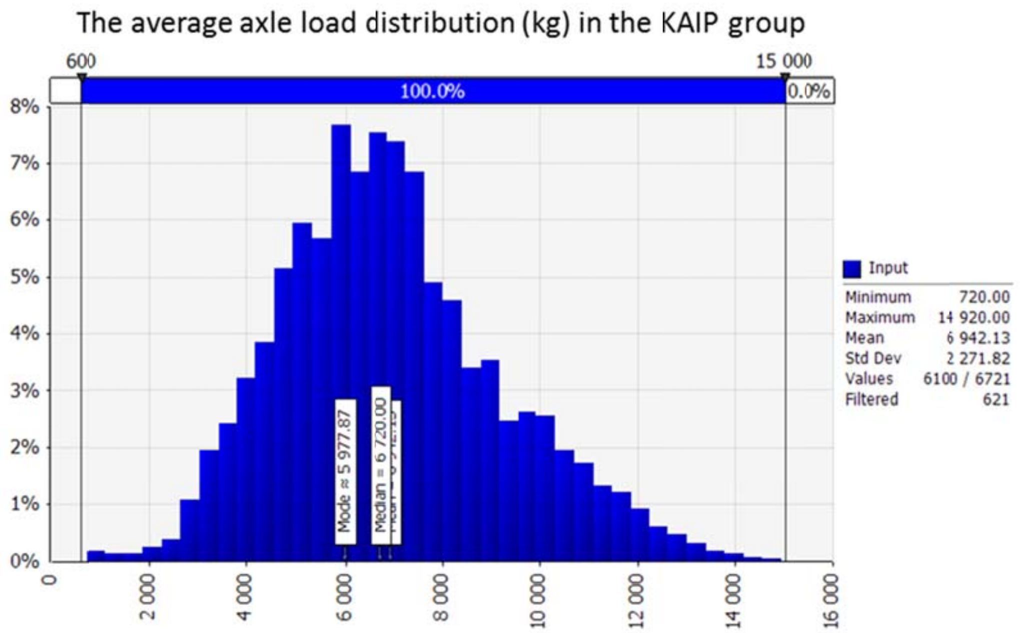


Figure 36. *The average axle load distribution (kg) in KAIP group excluding lifted axles.*

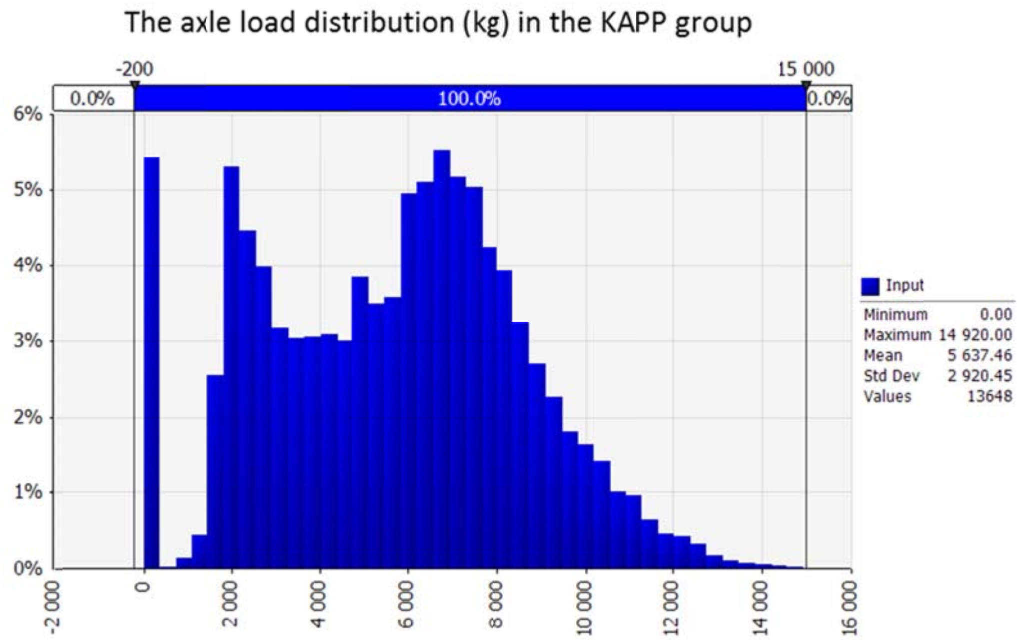


Figure 37. *The axle load distribution (kg) in the KAPP group including lifted axles (total of 742).*

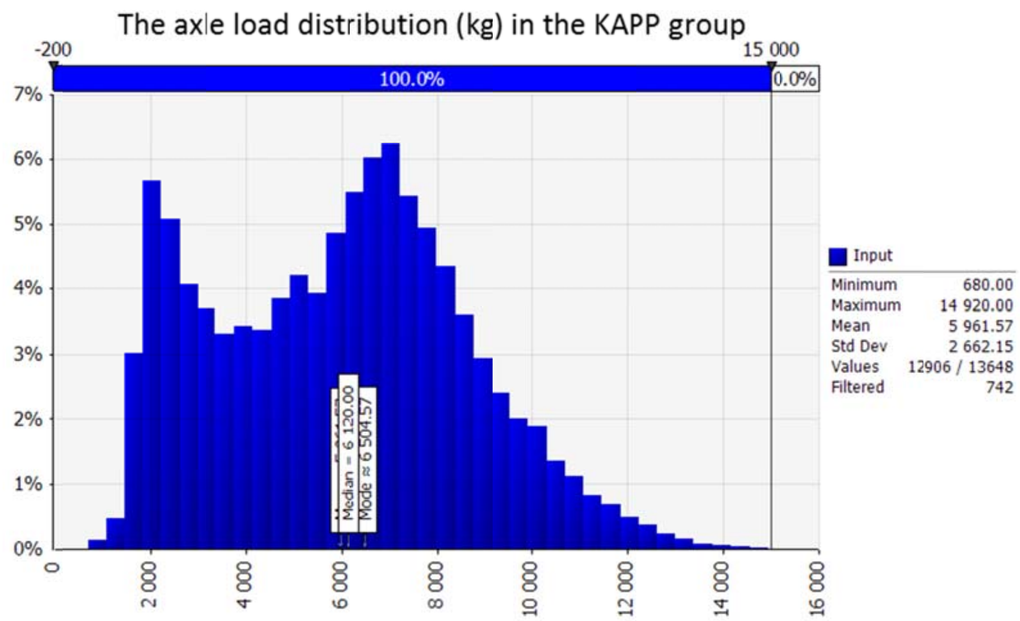


Figure 38. *The axle load distribution (kg) in the KAPP group excluding lifted axles.*

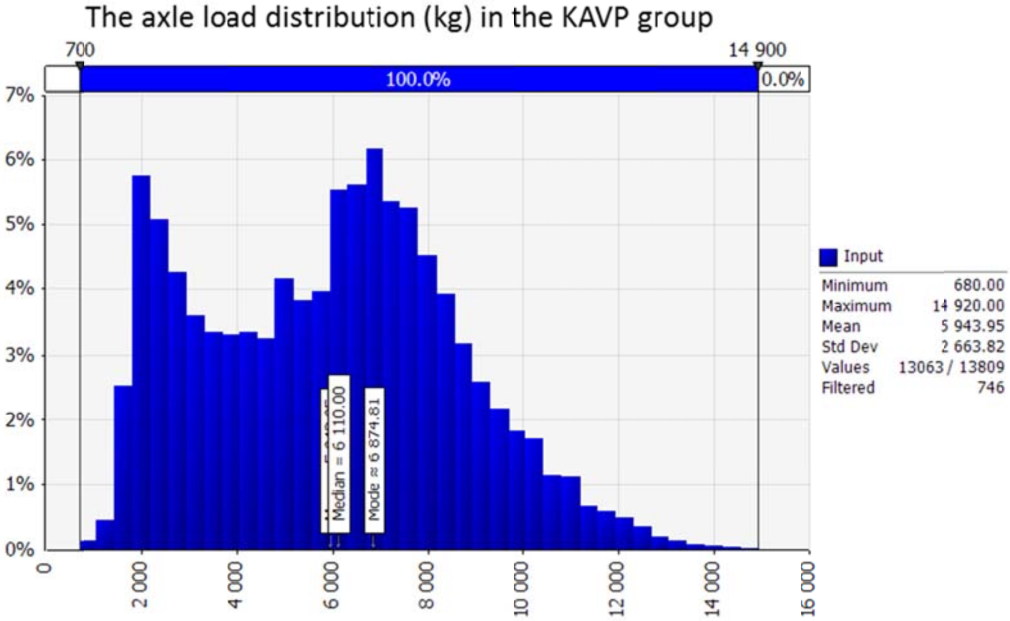


Figure 39. *The axle load distribution (kg) in the KAVP group excluding lifted axles (a total of 746).*

The average axle load of trucks was 6.9 tons and the average axle load of trailers was 5.1 tons.

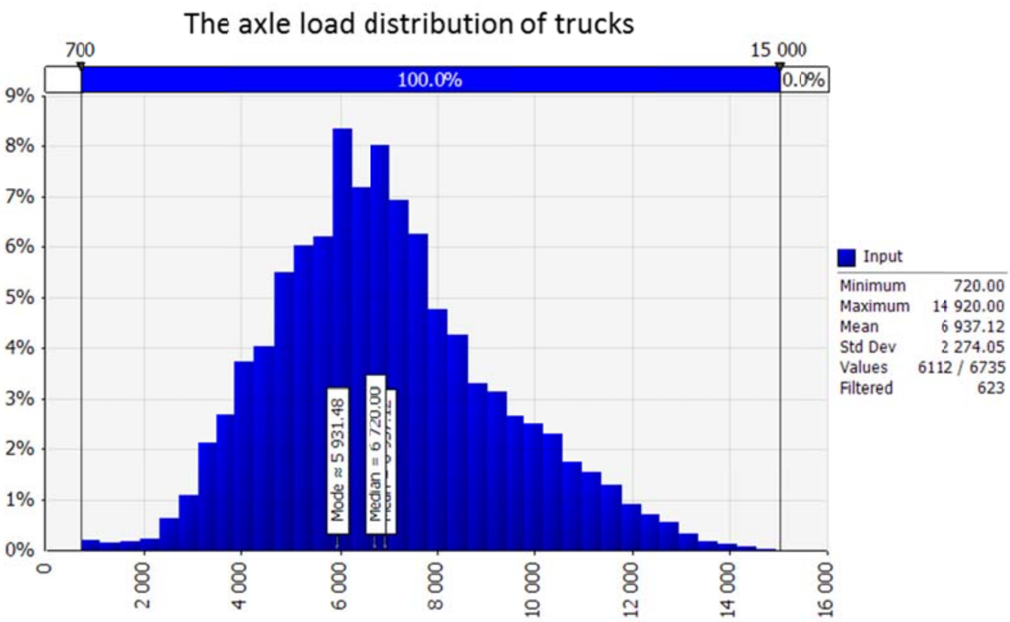


Figure 40. *The axle load distribution of trucks (kg).*

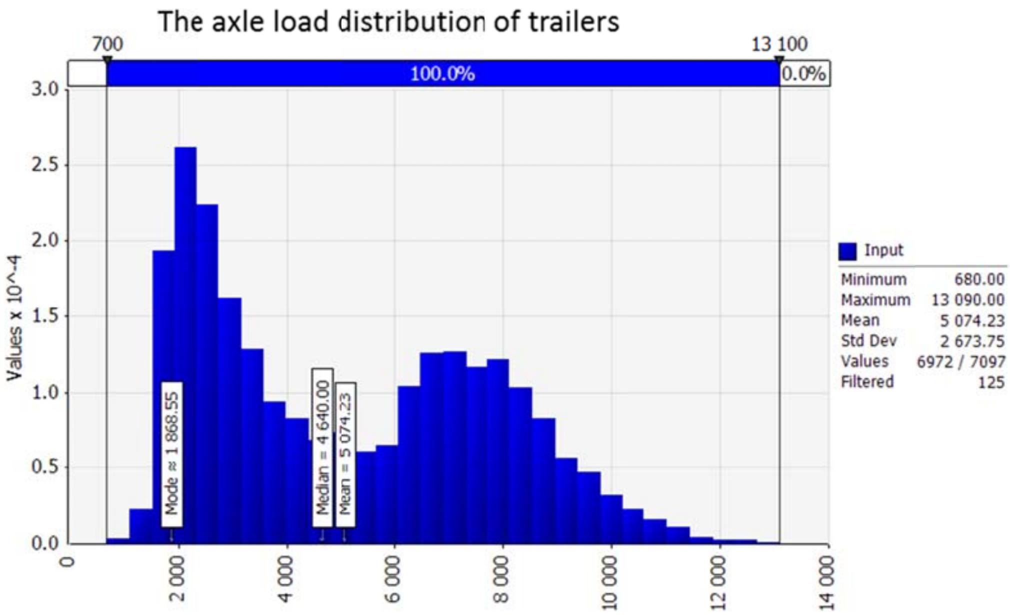


Figure 41. The axle load distribution of trailers (kg).

2.4.3 The distributions in relation to tire configuration

The axle loads of axles equipped with single tyres varied between 0.7 and 14.3 tons with an average of 5.4 tons. The axle loads of lifted axles have not been included in the distributions. The axle loads of super single axles varied between 0.8 and 12.8 tons with an average of 5.1 tons. The axle load of twin tyres axles varied between 1.0 and 14.9 tons with an average of 7.1 tons. The axle load distributions in relation to tire configuration are presented in figures 42–44.

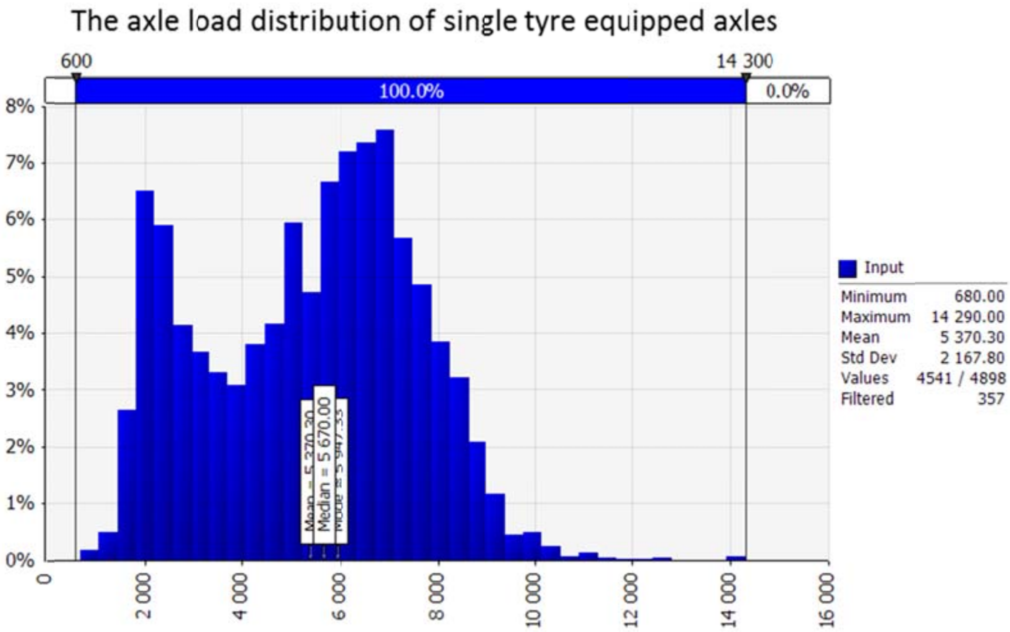


Figure 42. The axle load distribution (kg) of single tyre equipped axles.

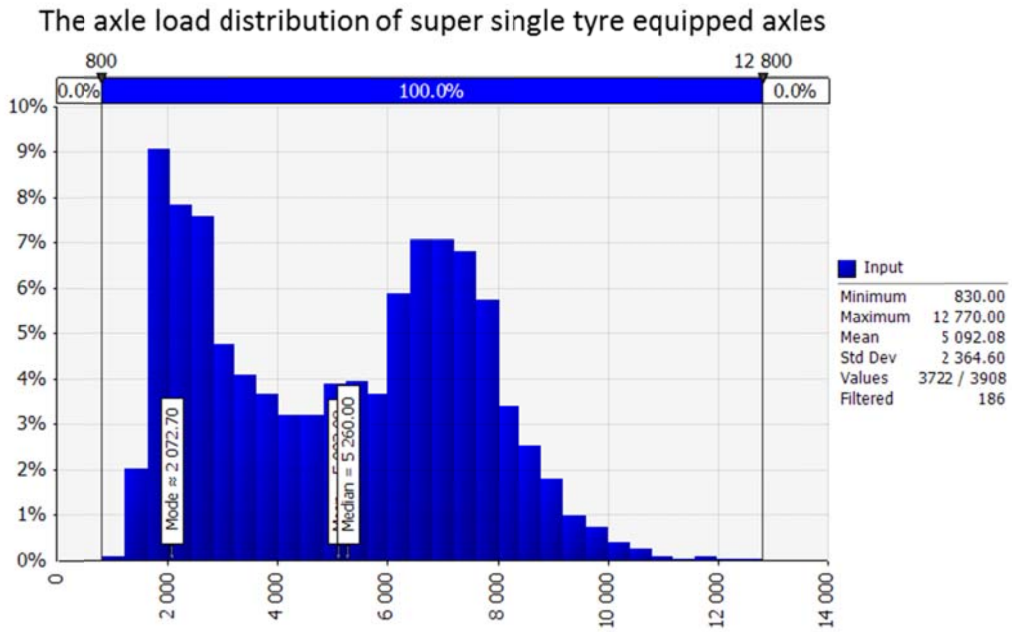


Figure 43. *The axle load distribution (kg) of super single equipped axles.*

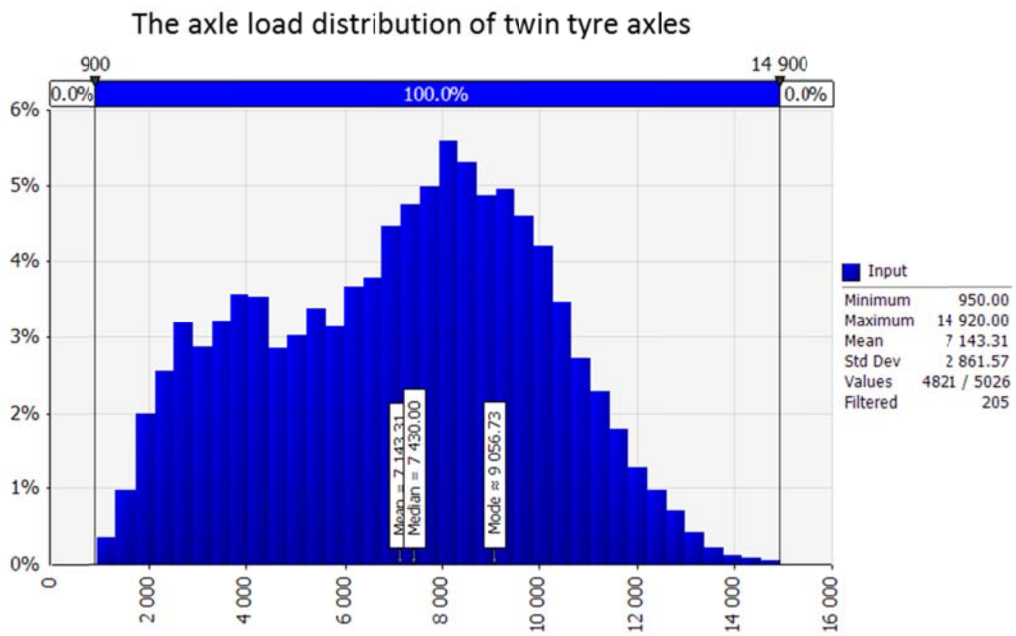


Figure 44. *The axle load distribution (kg) of twin tyre axles.*

2.4.4 The distributions in relation to drive shaft

The axle loads of front axles averaged 6.3 tons and varied between 1.2 and 12.6 tons. The axle load correlates with the normal distribution for a mean value of 6.3 tons and 1.3 ton standard deviation. The axle load of drive axles correlated with the normal distribution as well with an average of 7.9 tons and a 2.6 ton dispersion. The corresponding distribution adaptations are also included in figures 45 and 46.

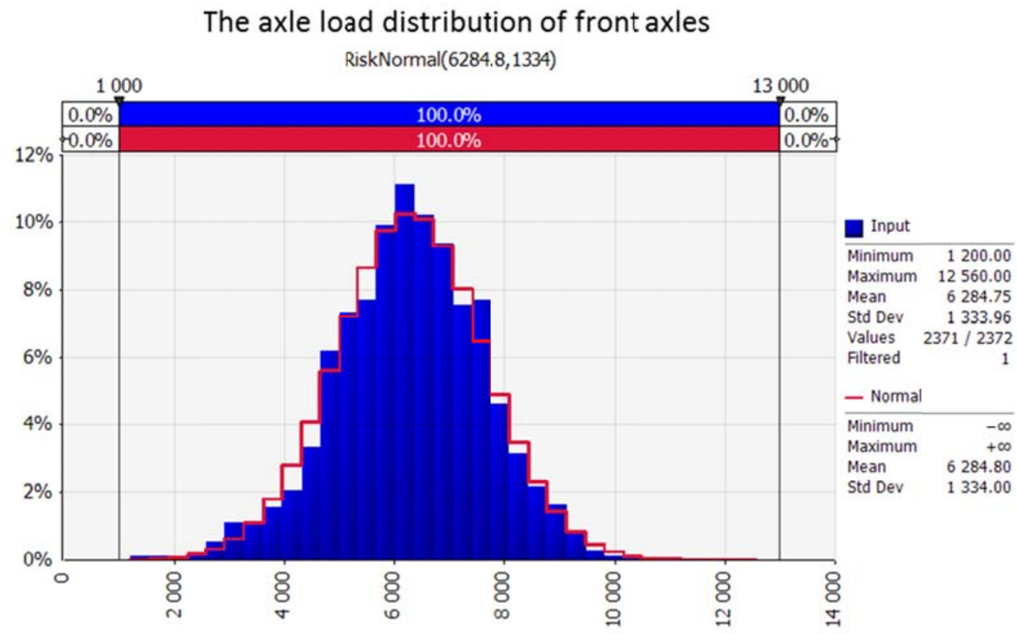


Figure 45. *The axle load distribution (kg) of front axles and their adaptation to the normal distribution.*

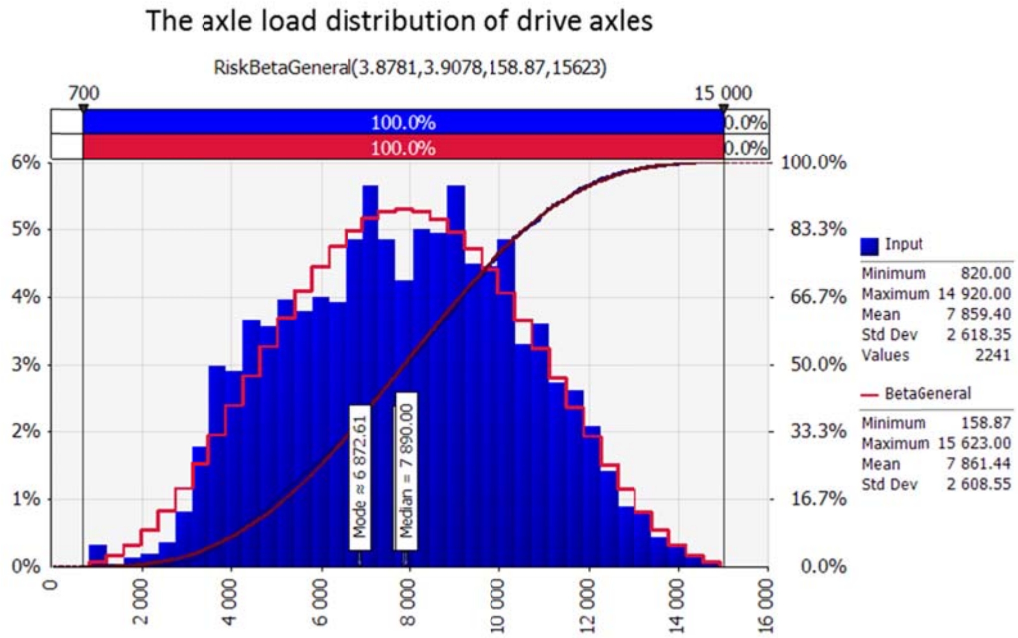


Figure 46. *The axle load distribution of drive axles and their distribution adaptation.*

2.4.5 The distributions in relation to suspension

The axle load distribution of air suspended axles has two peaks (figure 47). The masses vary between 0.7 and 14.9 tons. The mass distribution of leaf suspended axles (figure 48) is more consistent, has only one peak, and its varying range is the same.

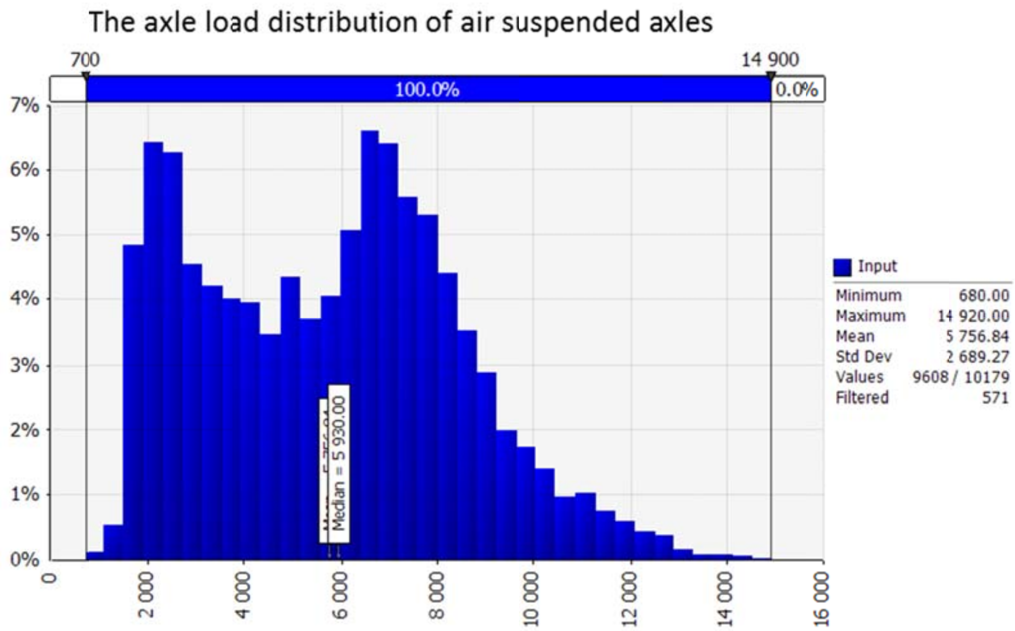


Figure 47. The axle load distribution of air suspended axles.

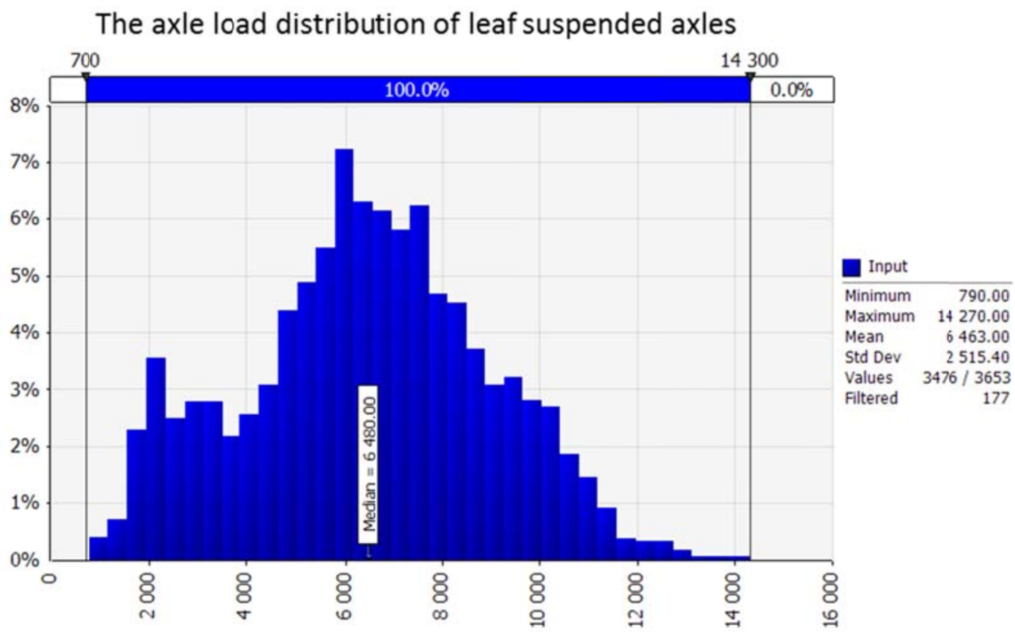


Figure 48. The axle load distribution of leaf suspended axles.

2.4.6 The distributions in relation to loading grade

The axle load distributions of vehicle groups with empty and fully loaded vehicles are represented separately in the following figures (figures 49–54). The average axle loads and their range of fully loaded vehicles are naturally higher than the respective values for empty vehicles. Vehicles that were reported as semi loaded have been excluded from this review.

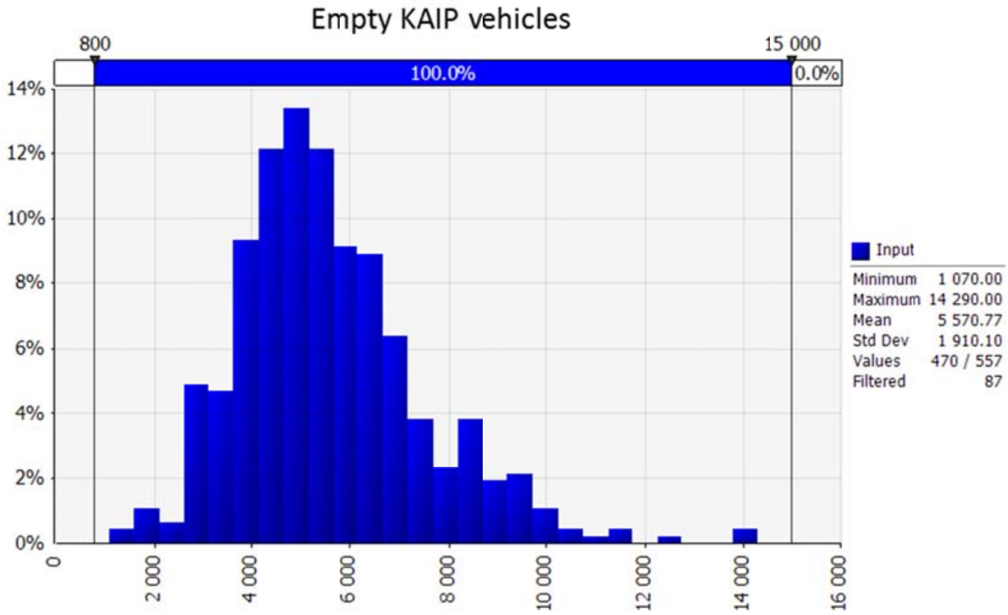


Figure 49. *The axle load distribution of empty KAIP vehicles.*

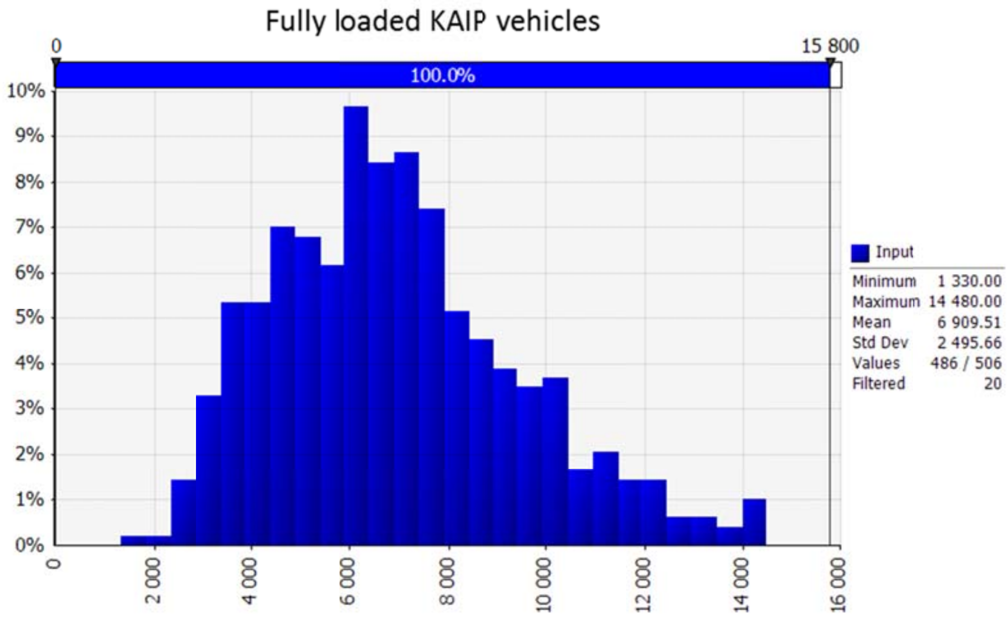


Figure 50. *The axle load distribution of fully loaded KAIP vehicles.*

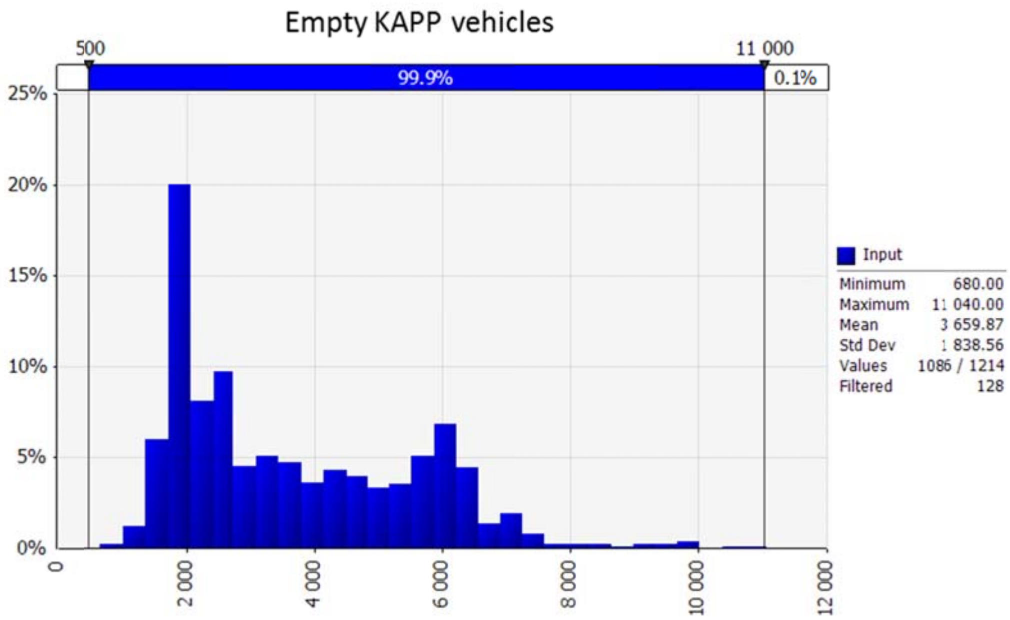


Figure 51. The axle load distribution of empty KAPP vehicles.

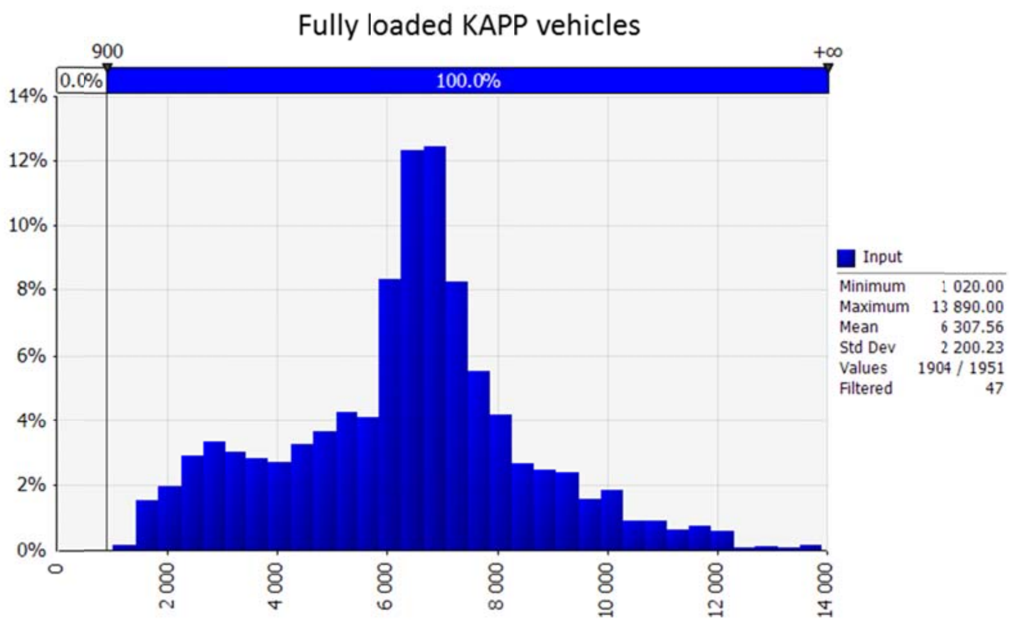


Figure 52. The axle load distribution of fully loaded KAPP vehicles.

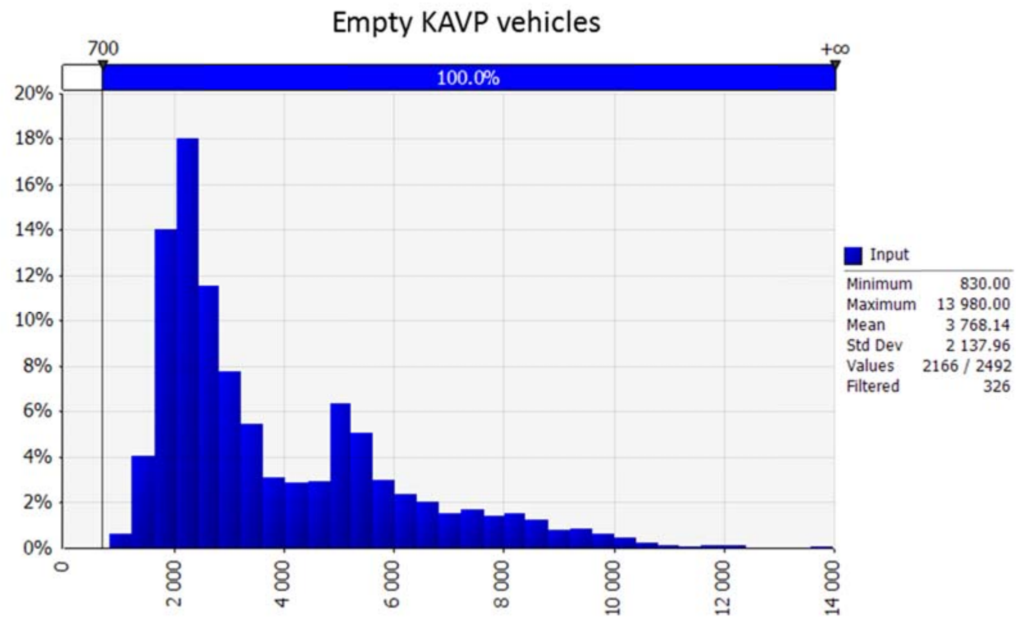


Figure 53. The axle load distribution of empty KAVP vehicles.

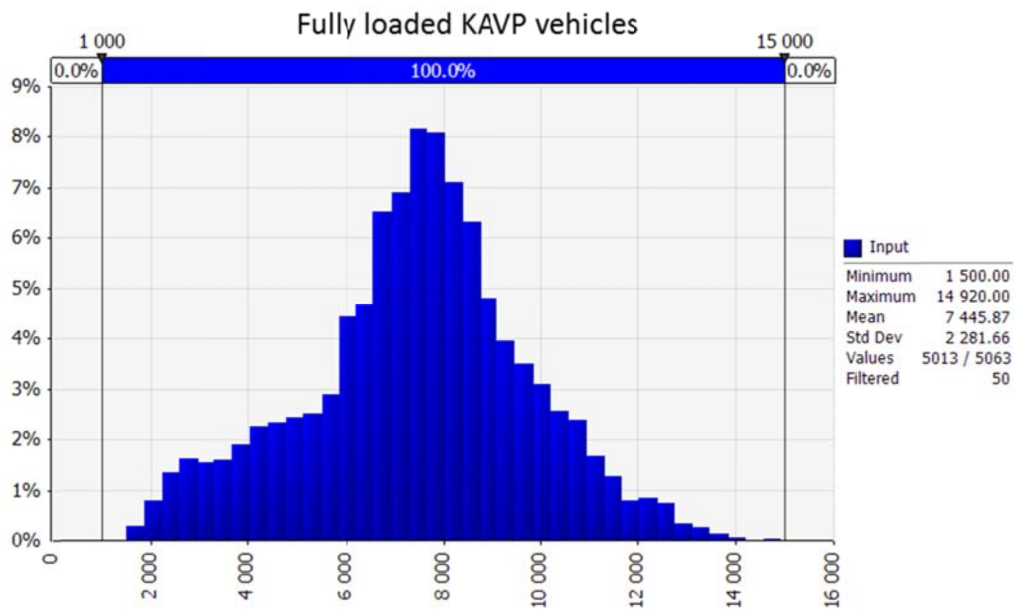


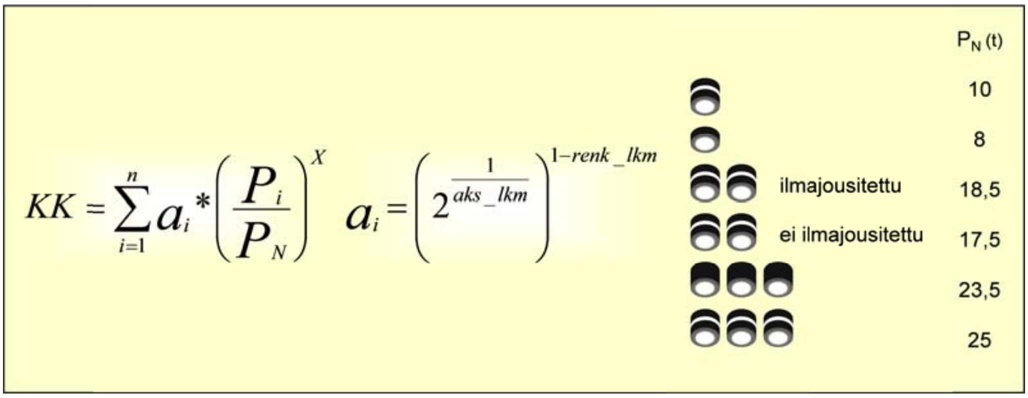
Figure 54. The axle load distribution of fully loaded KAVP vehicles.

2.5 Load equivalents

2.5.1 The basics for calculation

The correlation coefficient method means that each axle and vehicle class has its own correlation coefficient. The corresponding traffic volume, by class, is calculated to correspond with the standard axle's (single 100 kN twin tire axle) passes through the road's cross section. The calculated values are added together, yielding the load equivalent value produced by the entire traffic flow (in standard axles). When the daily load equivalent values are multiplied by the daily heavy traffic flow, the cumulative load equivalent value *KK* is produced, which yields primary data for load endurance reviews.

The load factors – which represent load equivalence – of the vehicles were calculated according to the principles presented in figure 55 with the exception that the variable a_i was not used. Calculating the factor was based on an axle/tyre type specific reference weight and the fourth power formula (x=4). The exponent represents the slope of the road structure's fatigue line. Different road structures may have altering slopes for the fatigue line, but the value of 4 is the most commonly used. The axle and bogie weights of each vehicle were divided by the reference weight (P_N), which was dependent on the type of bogie, suspension type and tyre type (table 17). A vehicle's load correlation is the sum of the load correlations of its axles. The average load correlation of a vehicle group is the average of correlations of every vehicle in the group.



aks_lkm = amount of axles
renk_lkm = amount of tyres
ilmajousitettu / ei ilmajousitettu = is air suspended / is not air suspended

Figure 55. The formula for calculating load equivalence for axles [2].

The reference weights used for calculating load equivalents are presented in table 16. The values presented in black are generally recognized values for reference weights. The values presented in red are separately interpolated or deduced values for this particular study.

Table 16. Reference weights (P_N) for different axle and tire configurations.

Axles / Bogie	Double		Supersingle		Single		Exponent
	DI	DM	SSI	SSM	SI	SM	
1	**10000**	9700	9000	8700	**8000**	7700	4
2	**18500**	**17500**	17390	16406	14800	13892	4
3	**25000**	**24000**	**23500**	**22500**	20000	19052	4
DI=double+air, DM=doube+other etc. ...							

There are two notable things that must be considered when calculating load equivalents– different bogie and tyres configurations vary more than before while the rules for calculating have barely changed at all. The formula assumes that all the tyres in a bogie are the same type. This means that the formula is not as reliable when calculating load equivalents for bogies with mixed tyre types. Calculating the load equivalent for a two axle bogie was based on a reference weight, which was determined by the tyre/suspension configuration of the first axle in the bogie. There were a few such mixed tyre/suspension configurations in the bogies, which could not be taken into consideration. In order to achieve more reliable results in load equivalent calculations, the computing rules should be updated accordingly.

Table 17 shows how different axle and tyre configurations in the vehicle population exist, all of which should have clear basics for calculating their corresponding load equivalents. The material contained a small amount of mixed situations where different types of tyres belonged to a single bogie. These are not shown in the table.

Table 17. The number of axles in different suspension, tyre, and axle type configurations.

Axles / Bogie	Double		Supersingle		Single		Total
	DI	DM	SSI	SSM	SI	SM	
1	604	150	31	14	1119	1319	3237
2	2305	1205	1290	230	1170	112	6312
3	405	305	1740	169	1502	91	4212
4	9	31	4	8	1	7	60
5		5					5
6		6					6
All	3323	1702	3065	421	3792	1529	13832
	5025		3486		5321		
	36 %		25 %		38 %		

Table 18. Average bogie masses for different suspension, tire, and axle type configurations.

Axles / Bogie	Double		Supersingle		Single		Total
	DI	DM	SSI	SSM	SI	SM	
1	6802	6184	5659	6579	6238	6271	6350
2	14026	13933	9334	9535	8748	8263	11813
3	20025	18356	13761	12364	12088	10793	13982
4	12773	18324	7340	18780	21320	31286	18382
5		53220					53220
6							30870

2.5.2 The load equivalents of axle configurations

The average load equivalents of axle and tyre type configurations varied between 0.31 and 1.25 (table 19). The average load equivalent of single axles was 0.51 with the smallest equivalent belonging to twin tyre configurations and the highest belonging to super single tyres paired up with iron suspension. Two axle bogies had an average load equivalent of 0.60 where the smallest belonged to air suspended super single tire configurations and the highest belonged to leaf suspended single tire configurations. The average load equivalent of three axle bogies was 0.44 with the smallest equivalent belonging to air suspended super single configurations and the highest belonging to leaf suspended single tire configurations. When comparing these values one must remember that behind each average there is a different amount of axles and different loading grades.

Table 19. Average load correlations for different axle and tire configurations.

Axles / Bogie	Double		Supersingle		Single		Total
	DI	DM	SSI	SSM	SI	SM	
1	0,42	0,42	0,47	0,81	0,48	0,57	0,51
2	0,55	0,79	0,31	0,51	0,82	1,12	0,60
3	0,67	0,64	0,32	0,36	0,45	1,25	0,44

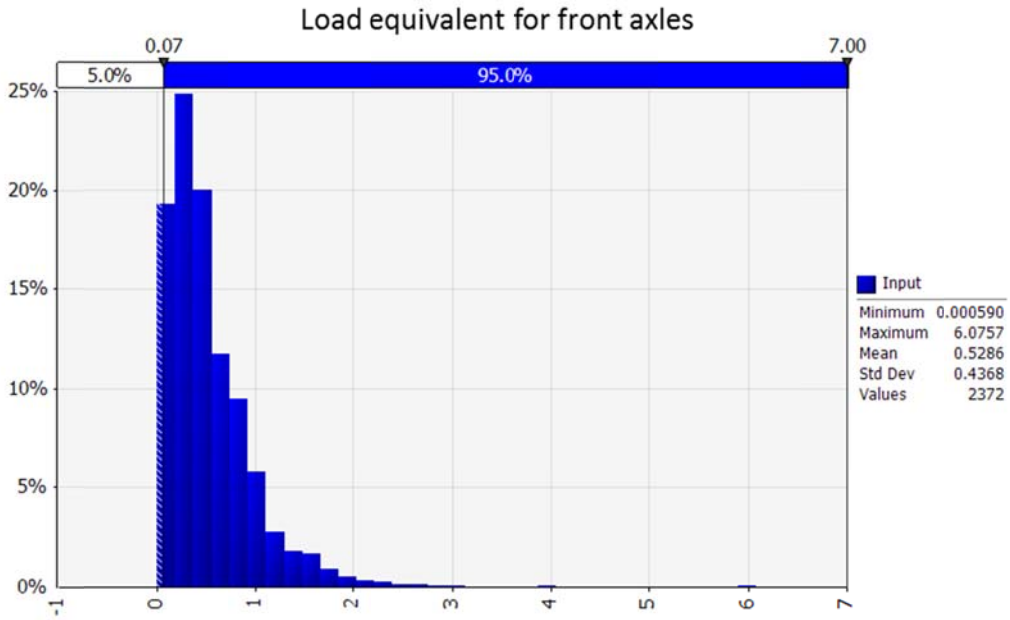


Figure 56. The load equivalent values for front axles.

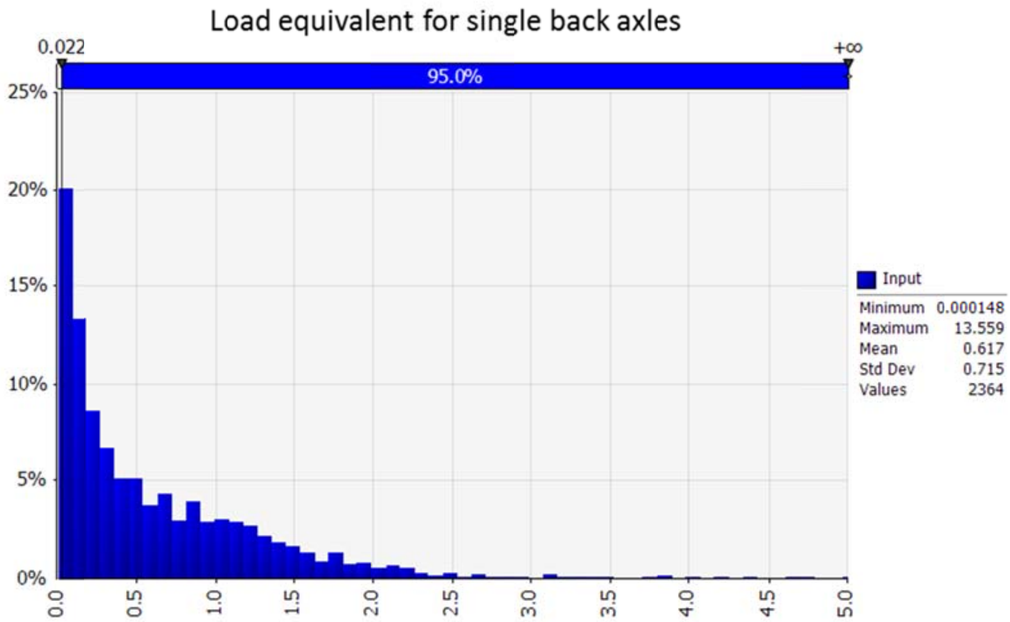


Figure 57. The load equivalent values for single axle back axles.

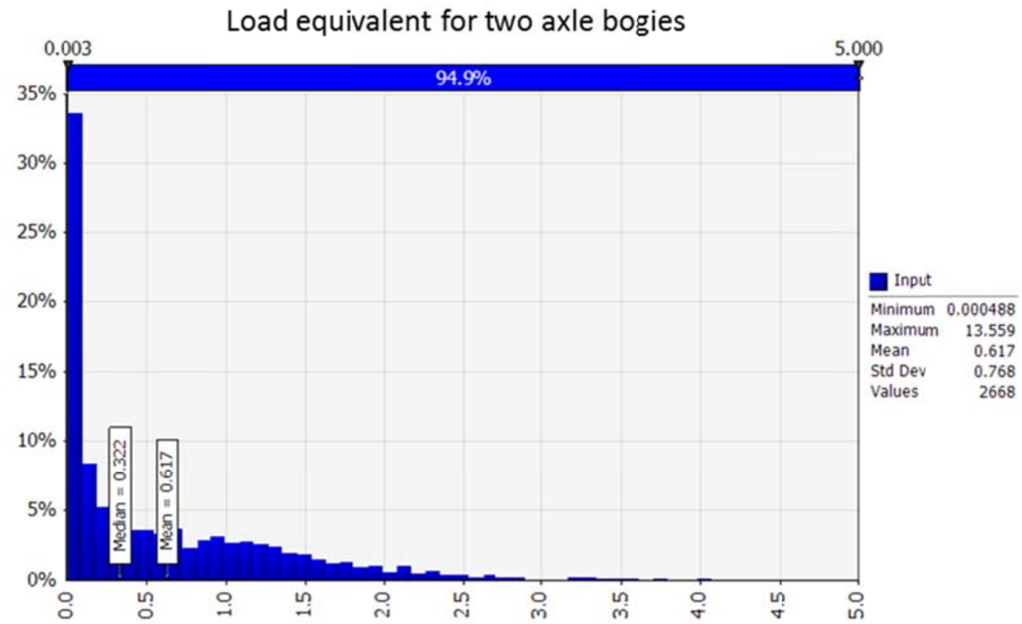


Figure 58. *The load equivalent values for two axle bogies.*

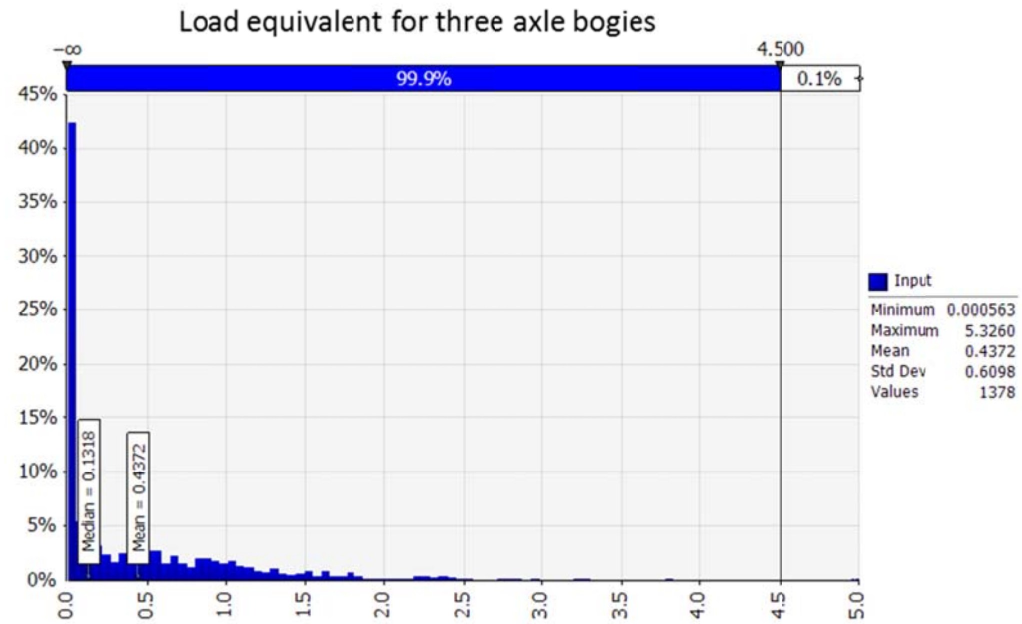


Figure 59. *The load equivalent values for three axle bogies.*

2.5.3 Load equivalents per vehicle group

The average load equivalents per vehicle groups were 0.88, 1.29, 2.46, and 1.83 (table 20). The respective values by loading grade are presented in the table as well.

Table 20. The average load equivalents per vehicle group

Load	Vehicle group			
	Trucks	Semitrailers	Full trailers	Modules
Empty	0,62	0,48	0,69	0,77
Semi full	0,70	1,02	1,60	1,01
Full	1,28	1,86	3,54	2,56
Average	0,88	1,29	2,46	1,83

The load equivalent is both dependent on axle/suspension/tyre configurations as well as tyre/bogie masses. Therefore there is a lot of variation within vehicle groups. The load equivalent of a singular vehicle may vary from zero to even 10 standard axles depending on the loading grade (figure 60). In the review presented in the figure, the loading grade is determined by dividing the GVW of the vehicle by the sum of its maximum allowed axle weights. The sum of maximum allowed axle weights may not always amount to the vehicle specific maximum GVW. The maximum allowed GVW may be smaller than this amount, but this has not been taken into consideration in this review. In extreme cases, the load equivalents of vehicles without trailers may reach the same level as the load equivalents of module combinations.

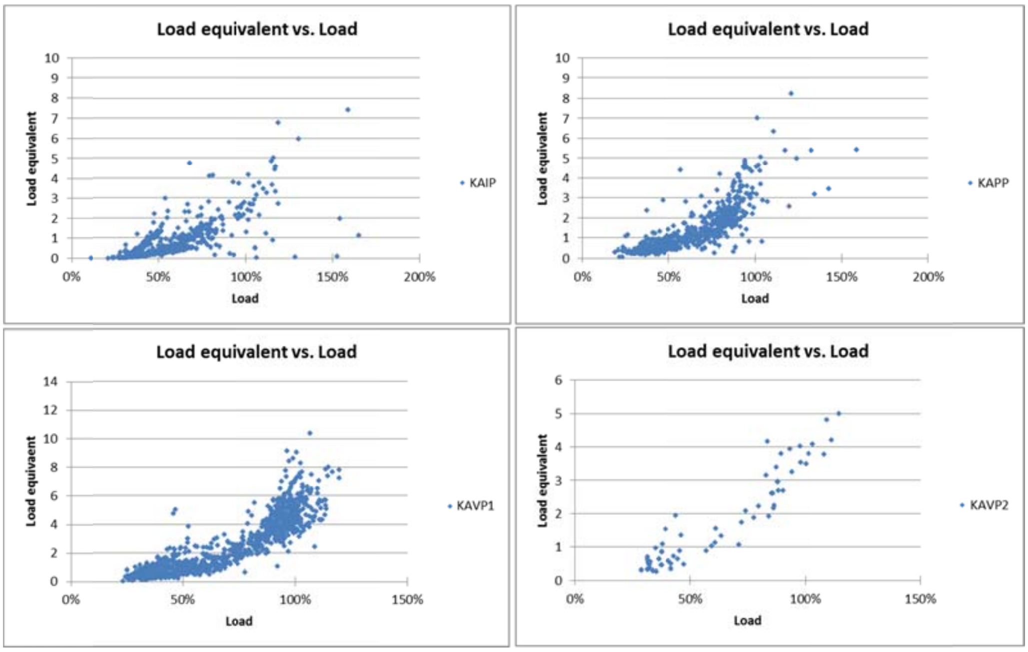


Figure 60. The calculated loading grade based on load equivalents in relation to the theoretical maximum axle loads.

The load equivalent based on GVW and the reported loading grade of singular vehicles is presented in figure 61. The GVW and load equivalent of fully loaded vehicles varied noticeably depending on the weight of the cargo. The load equivalent of close to 80 modules varied between 4 and 9 standard axles.

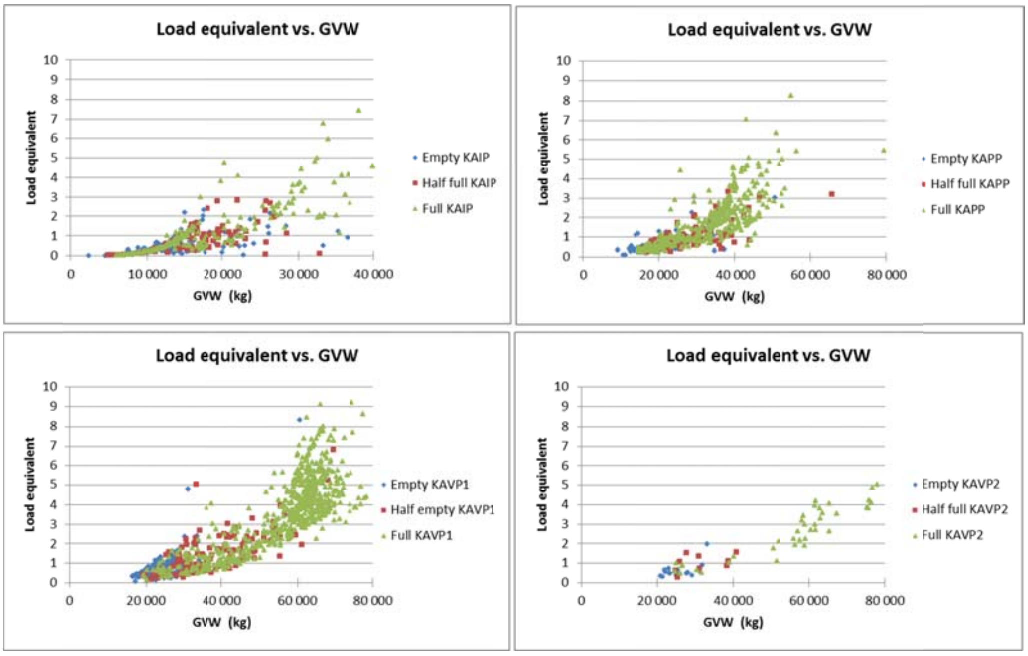


Figure 61. *Load equivalent in relation to GVW per loading grade.*

2.5.4 Load equivalent by cargo type

The load equivalents and GVWs of vehicles per cargo type are presented in the following tables 62–66. In the 2014 measurements, round timber and soil transports have been separated from each other. In the 2013 measurements they are combined as raw material transports.

One can assume from the figures that the loading grade of some vehicles is either reported falsely or recorded incorrectly. Such individual results have not been considered in post examination as they are not reliable.

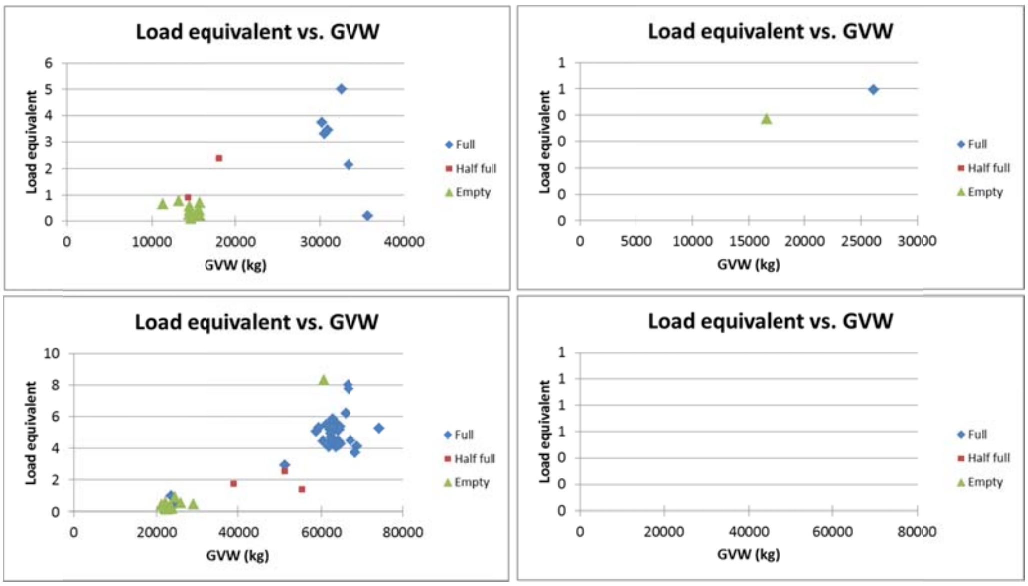


Figure 62. *Load equivalent in relation to GVWs per loading grade for soil transports.*

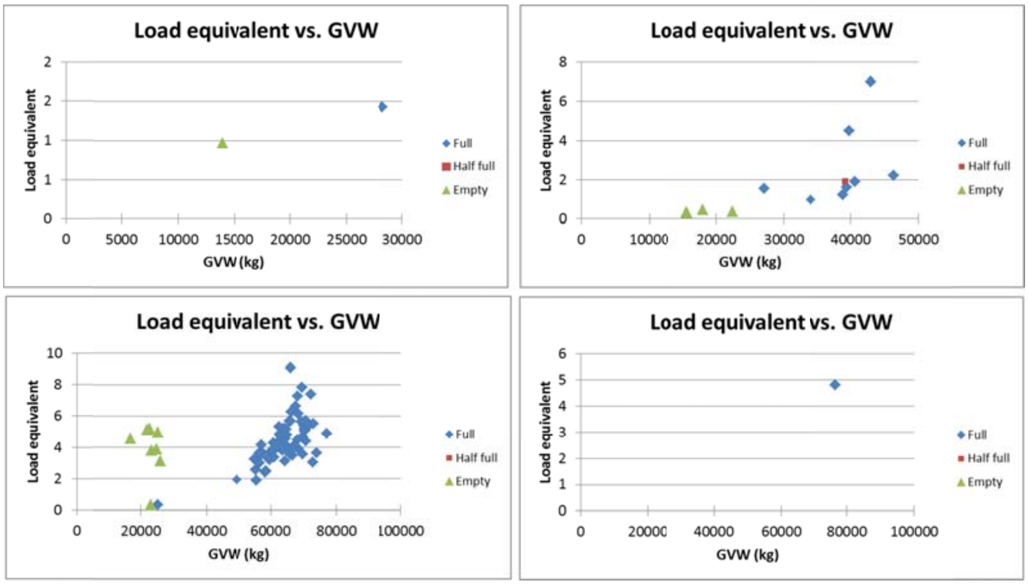


Figure 63. *Load equivalent in relation to GVW per loading grade for round timber transports.*

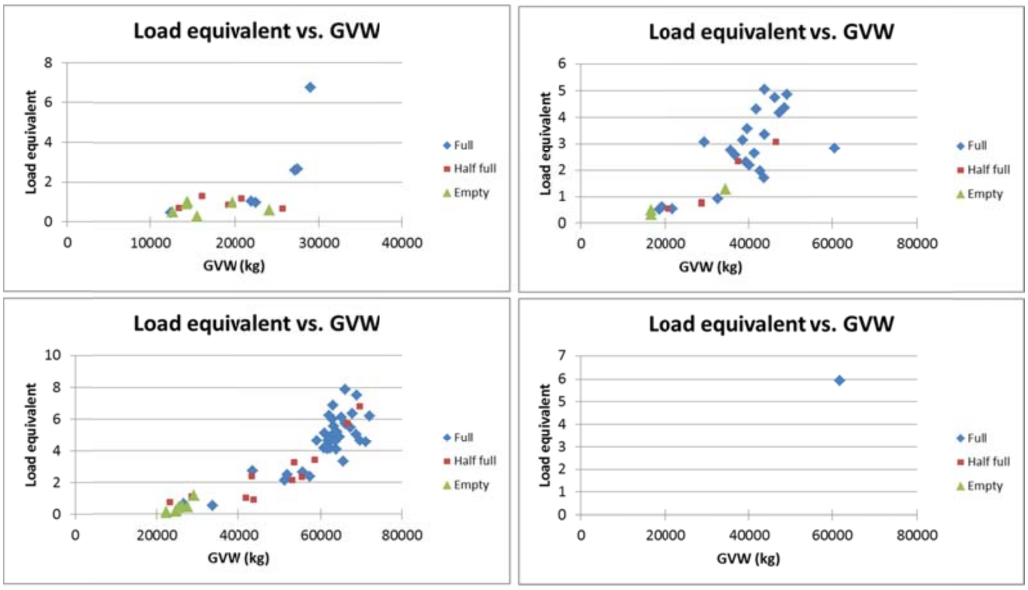


Figure 64. *Load equivalent in relation to GVW per loading grade for raw material transports.*

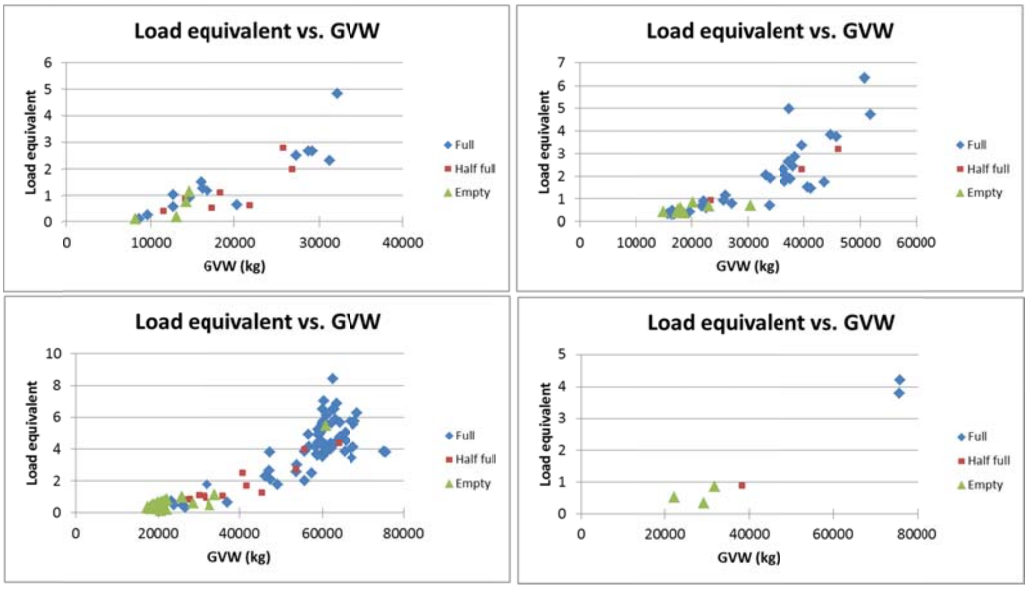


Figure 65. *Load equivalent in relation to GVW per loading grade for liquid transports.*

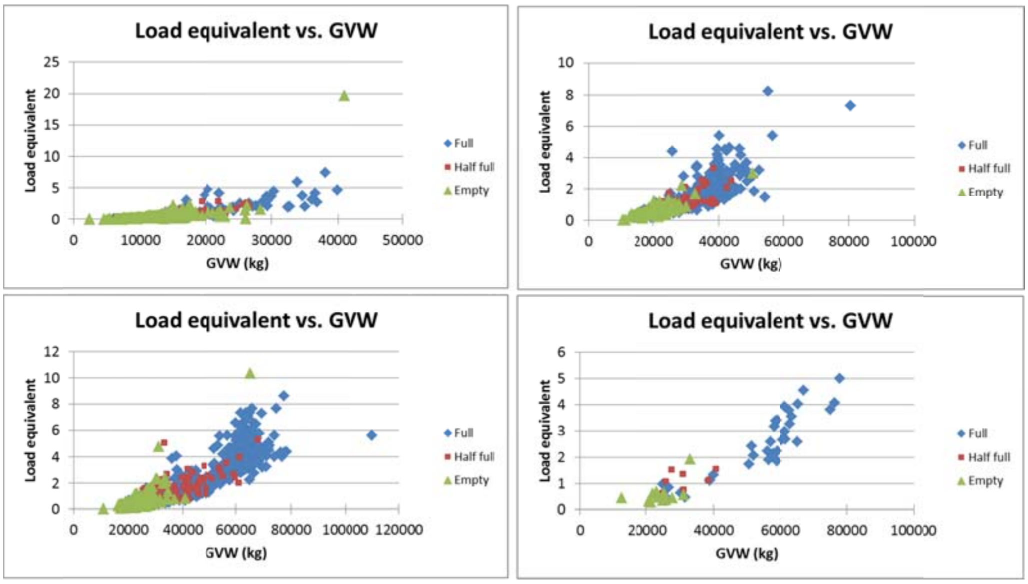


Figure 66. *Load equivalent in relation to GVW per loading grade for other transports.*

2.5.5 KAIP

The average load equivalent value for vehicles without trailers is 0.88 and it varied between 0 and 19.6.

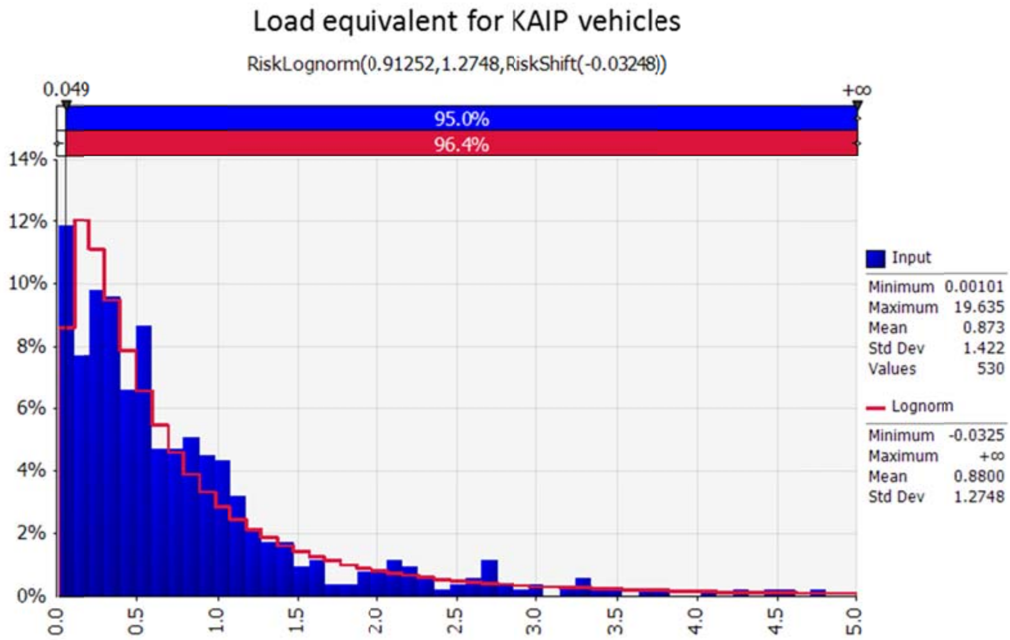


Figure 67. The load equivalent of vehicles without trailers raised to the power of 4.

2.5.6 Other vehicle groups

The average load equivalent for semi-trailers was 1.75 and varied between 0.1 and 15.5 standard axles.

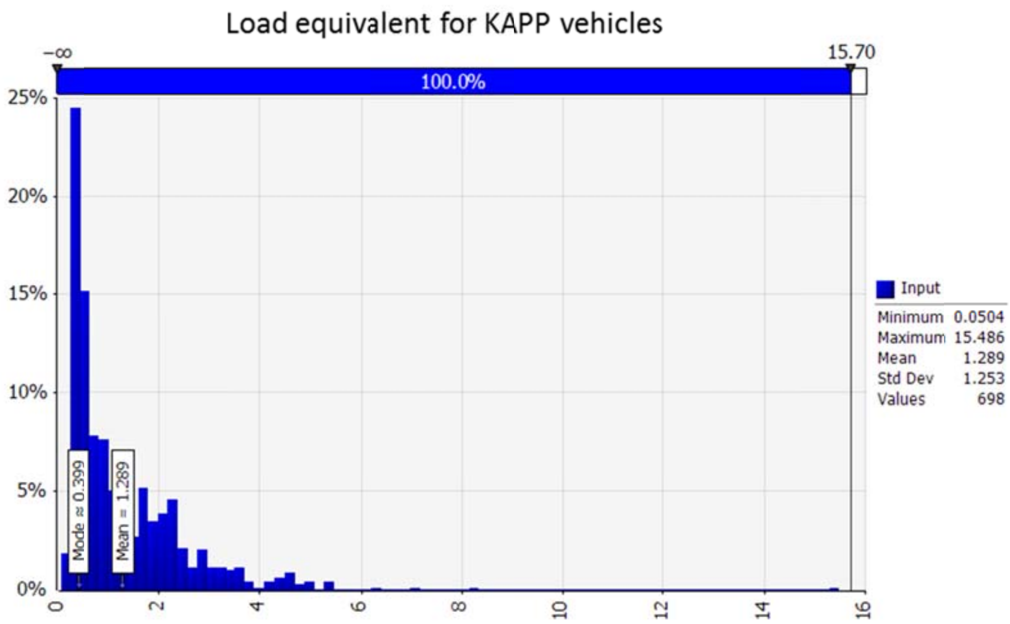


Figure 68. The load equivalent distribution of the KAPP group.

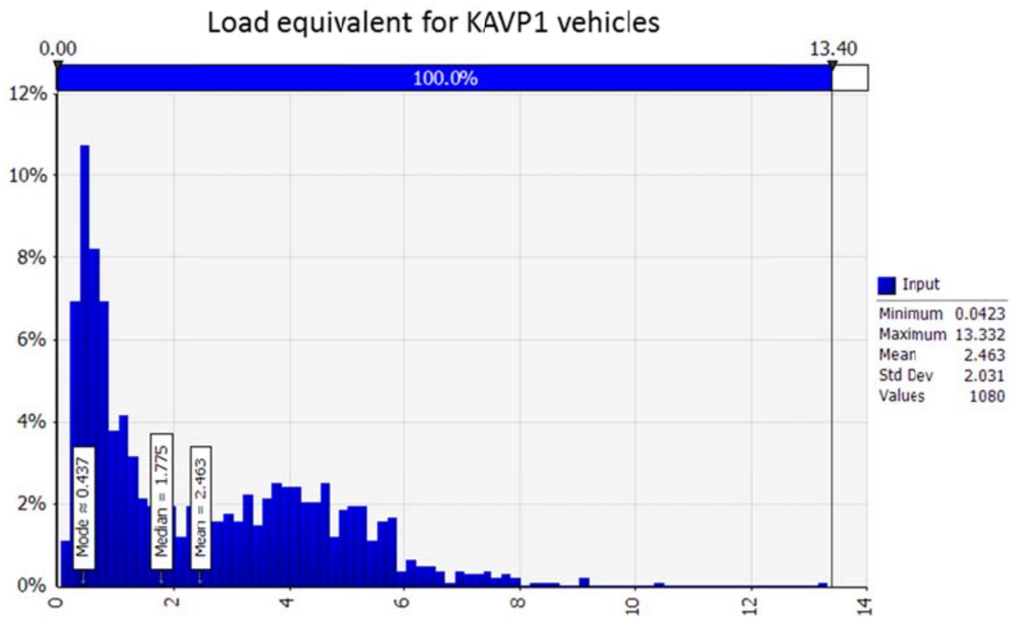


Figure 69. The load equivalent distribution of the KAVP1 group.

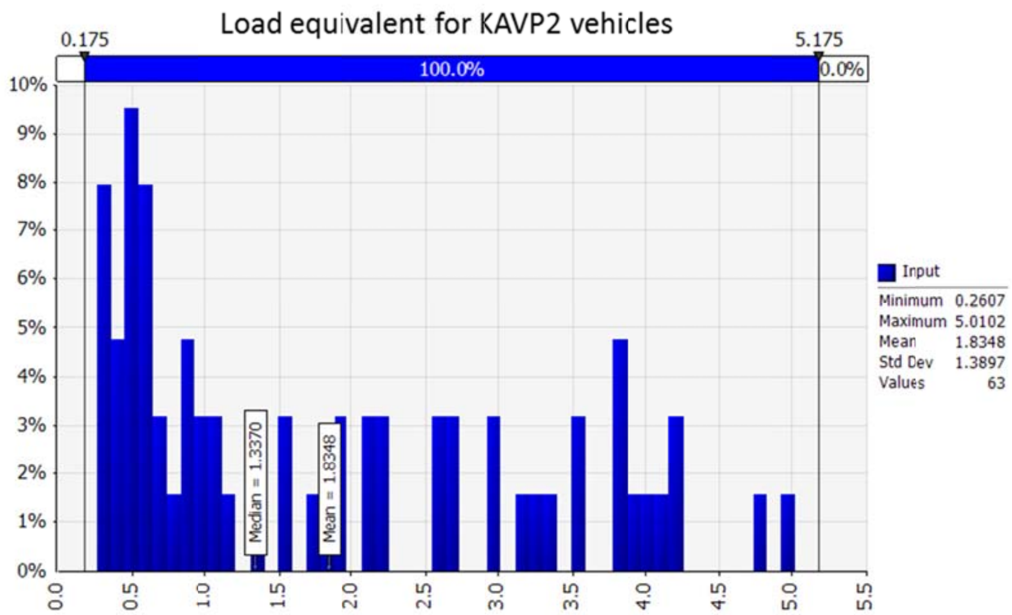


Figure 70. The load equivalent distribution of module combinations.

2.6 Changes in load equivalent values

Vehicle group specific load equivalent values used in the study as well as the respective values from the previous study are presented in the following table (table 21).

Table 21. Vehicle group specific load equivalent changes.

Type	Picture	ESAL	
		2014	1999
KAIP		0.88	0.58
KAPP		1.29	1.48
KAVP		2.46	2.63
MODULE		1.83	-

According to the results, the load caused by individual axles has decreased in comparison to the previous study. Both vehicle groups and vehicle types have changed since the previous study. This change explains the decrease in load correlations in individual axles. Therefore, in the present day, masses are usually divided between more axles than before. Changes that have occurred within each vehicle group are presented in the following tables.

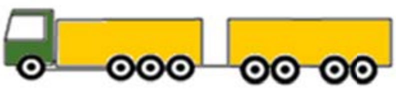
Table 22. Vehicle type percentages in the KAIP group.

Type	Picture	Fraction [%]	
		2014	1999
1		42.7	55.6
2		45.7	37.4
3		8.1	1.6
4		2.6	5.2
5		0.9	-

Table 23. Vehicle type percentages in the KAPP group.

Type	Picture	Fraction [%]	
		2014	1999
2+2		0.7	4.1
2+3		46.0	48.2
3+2		7.0	9.3
3+3		44.9	31.0
	Others	1.4	7.4

Table 24. Vehicle type percentages in the KAVP group.

Type	Picture	Fraction [%]	
		2014	1999
3+12		2.9	14.9
3+22		40.4	58.1
3+13		1.3	6.9
4+13		5.3	8.6
3+23		37.2	1.1
4+22		4.2	
4+23		4.2	
	Others	4.5	10.4

2.7 Other load equivalent values

Trafikia AB conducted vehicle mass measurements for the Finnish Transport Agency using the Bridge-WIM (Weight-In-Motion) at the same time as the axle load study was taking place. For later data comparison, load equivalents values for the results in this study were calculated additionally by using the ESAL (Equivalent Single Axle Load) formula used by Trafikia as well.

$$ESAL = \sum_{i=1}^{n} 10^{-4} * ft * fa * (P_i)^4$$

Essentially the formula follows the same principles as the formula used in this study. The variable *ft* is dependent on a vehicle's tire and suspension configuration and it is left out as tire and suspension types are not determined in the WIM measurements.

The variable *fa* is a factor dependent on the axle's reference weight and its value varies based on the amount of axles attached to a single bogie. The variable may receive a value of 1.0000 with a single axle, a value of 0.0953 with a dual axle, and a value of 0.0301 with a triple axle. These correspond with 10 ton, 18 ton, and 24 ton reference weights respectively and are very close to the air suspended twin tire axle reference weights used in the axle load study. Since the reference weights of air suspended twin tyres are greater than those in other suspension and tyres types (table 16) the formula usually produces a lower ESAL value for vehicles than the formula used in this study.

The differences in the load values produced by these two formulas in each of the vehicle groups are presented in the following figures. The prominent difference in the results is explained by the so-called "power of 4" rule, which raises the differences in reference weights to the power of four. The calculation of ESAL values and the differences between the calculation methods are explained more specifically with a few select vehicles in appendix 4.

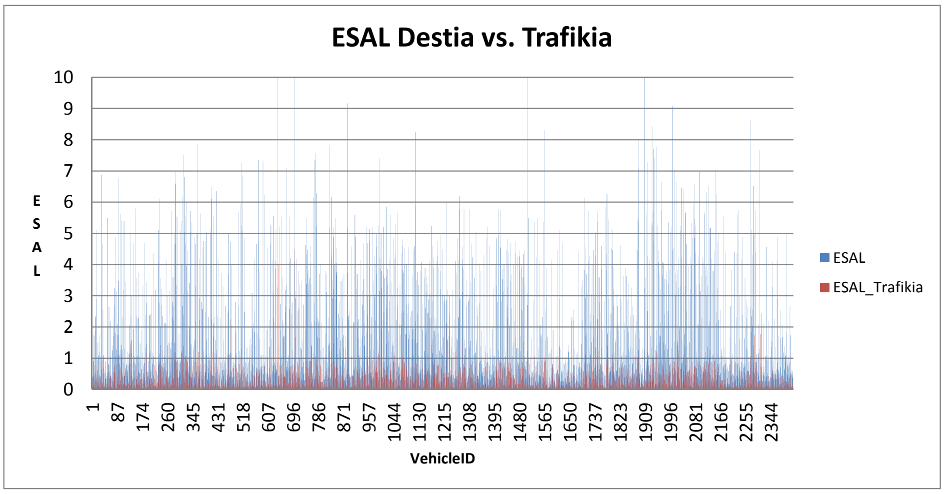


Figure 71. The comparison of vehicle specific ESAL values between the formula used by Destia (chapter 2.5.1, figure 55) and the formula used by Trafikia with vehicleID on the x-axis.

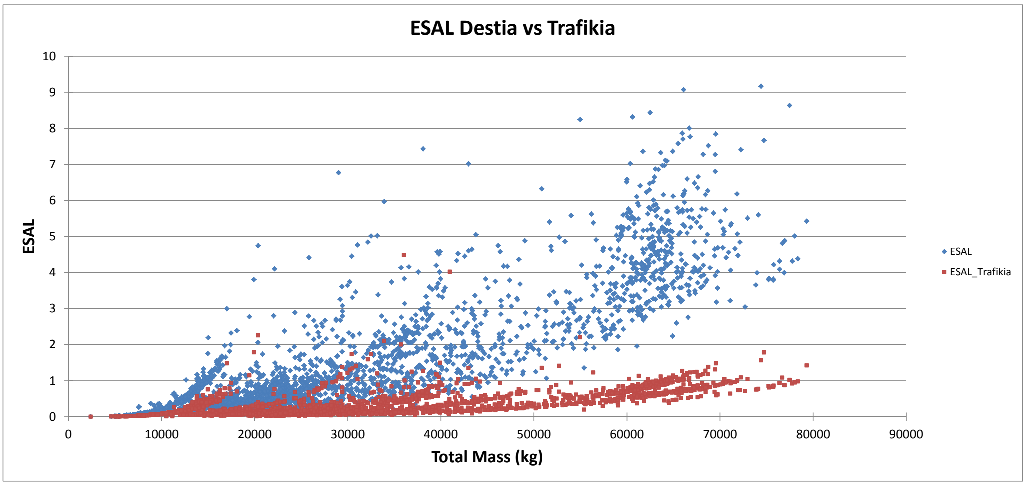


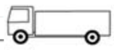
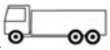
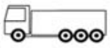
Figure 72. *The comparison of vehicle specific ESAL values between the formula used by Destia (chapter 2.5.1, figure 55) and the formula used by Trafikia with GVW on the x-axis.*

3 Primary data for simulation

3.1 Trucks without trailers

3.1.1 Axle distances and average axle loads

Table 25. The percentages and average axle distances (m) and axle/bogie masses (kg) in the KAIP group.

Type	KAIP	Fraction	1 axel	2 axels	3 axels	4 axels	Front Axel	Axel 2	Axel 3	Axel 4	Axel 5	Total Mass
	1	42,7 %					43,3 %	56,7 %				100 %
			5,00	-	-	-	4573	5979	-	-	-	10552
	2	45,7 %					31,8 %	40,4 %	27,7 %			100 %
			4,80	1,30	-	-	6279	7978	5468	-	-	19725
	3	8,1 %					26,4 %	25,3 %	25,9 %	22,4 %		100 %
			3,60	1,38	1,36	-	7009	6706	6860	5942	-	26517
	4	2,6 %					24,3 %	23,4 %	27,5 %	24,8 %		100 %
			2,86	2,23	1,33	-	5891	5687	6664	6026	-	24269
	5	0,9 %					19,6 %	20,6 %	21,4 %	20,8 %	17,6 %	100 %
			2,4	2,06	1,35	1,36	6468	6778	7040	6842	5790	32918
Axels that are up are not included in the averages.							Axels that are up are not included in the averages.					

3.1.2 The axle load distributions

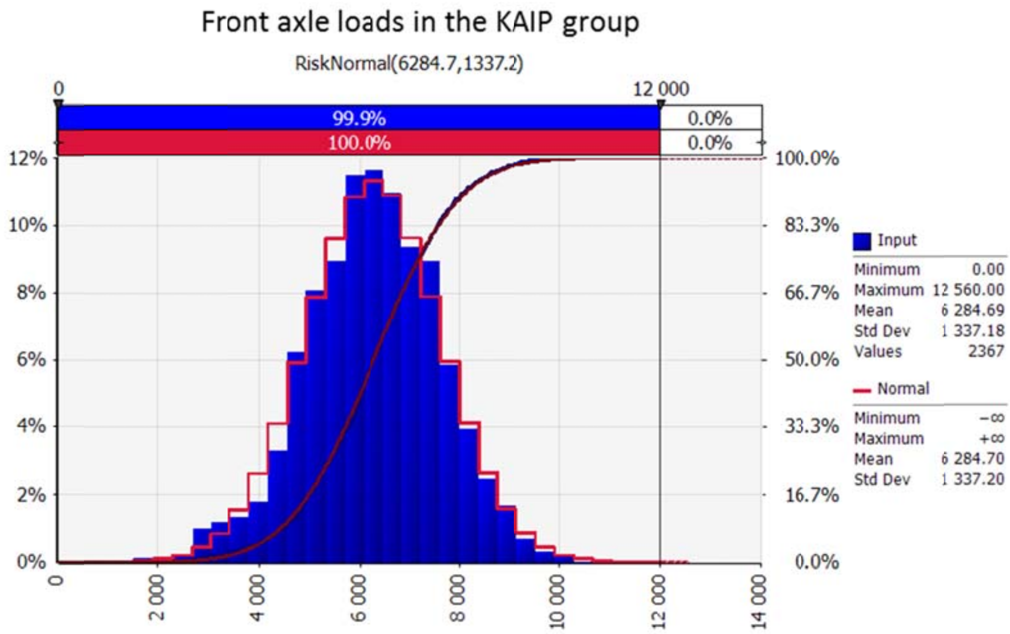


Figure 73. Front axle loads in vehicles in the KAIP group.

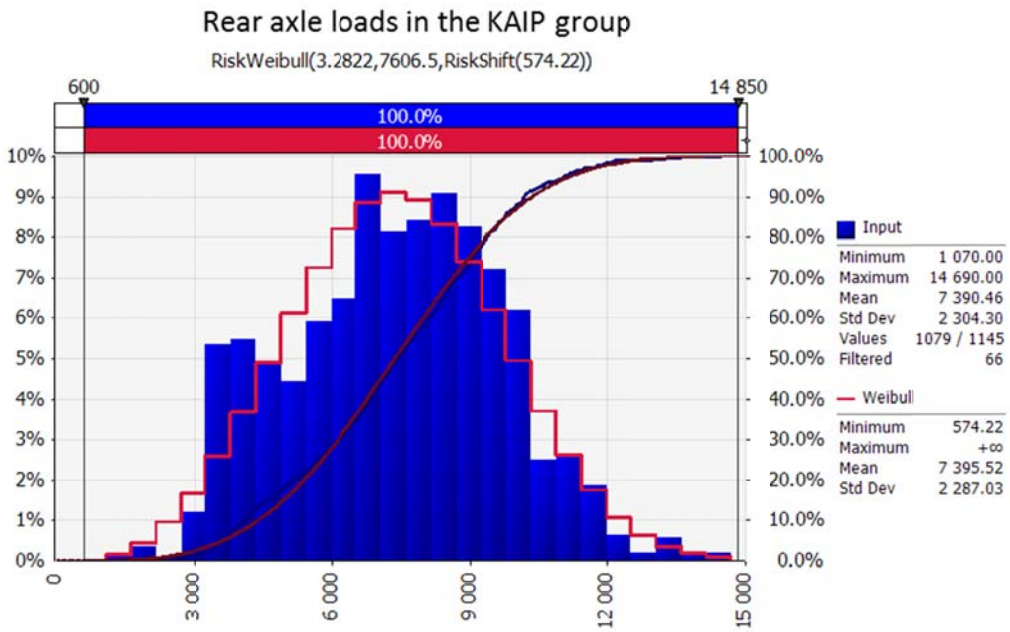


Figure 74. *Rear axle load of a two axle type 1 vehicle in the KAIP group.*

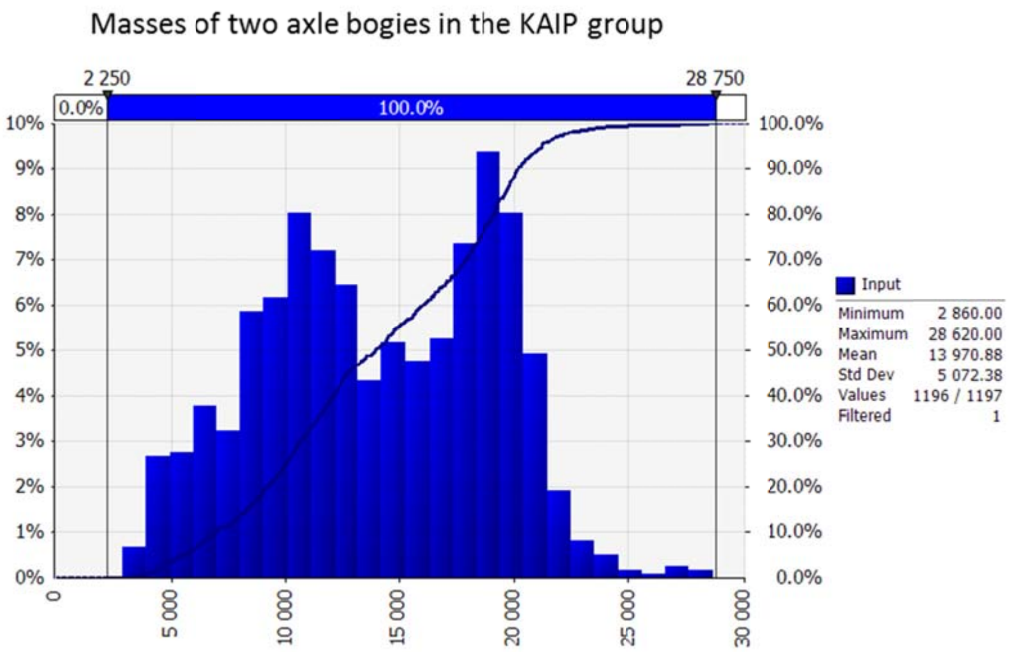


Figure 75. *Bogie mass of two axle bogies in the KAIP group (excluding raised axles).*

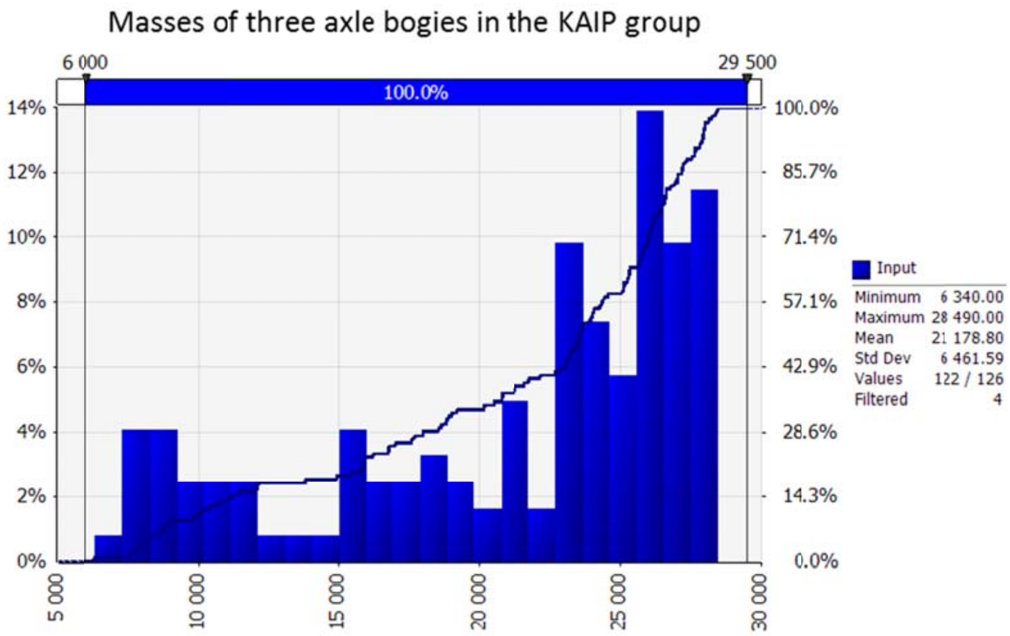


Figure 76. Masses of three axle bogies in the KAIP group (excluding lifted axles).

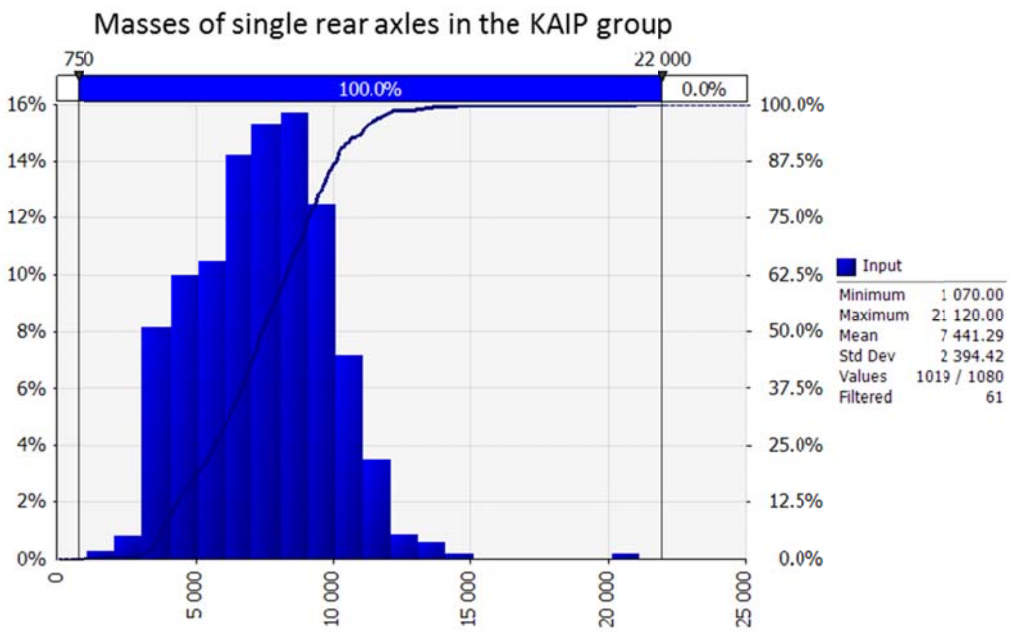


Figure 77. Masses of single axles (second axle) in the KAIP group.

3.2 Semi-trailer combination trucks (The KAPP group)

3.2.1 Axle distances and average axle loads

Table 26. The average axle distances and axle loads of semi-trailers.

Type	KAPP	Fraction	1 axel	2 axels	3 axels	4 axels	5 axels	Front Axel	Back Axel	Bogie	Total Mass
	1+11	0,0 %	-	-	-	-	-	-	-	-	-
	1+2	0,7 %	4,2	6,70	1,30	-	-	25,1 % 5765	32,3 % 7403	42,6 % 9770	100 % 22938
	1+3	46,0 %	3,8	5,70	1,30	1,30	-	24,7 % 6430	27,8 % 7248	47,5 % 12376	100 % 26054
	2+11	0,0 %	-	-	-	-	-	-	-	-	-
	2+2	7,0 %	4,3	1,30	6,60	1,50	-	22,6 % 6355	42,6 % 11973	34,8 % 9765	100 % 28093
	2+3	44,9 %	2,9	1,30	5,60	1,30	1,30	18,3 % 6112	41,8 % 13959	39,9 % 13329	100 % 33412
		98,5 %									

3.2.2 The axle load distributions

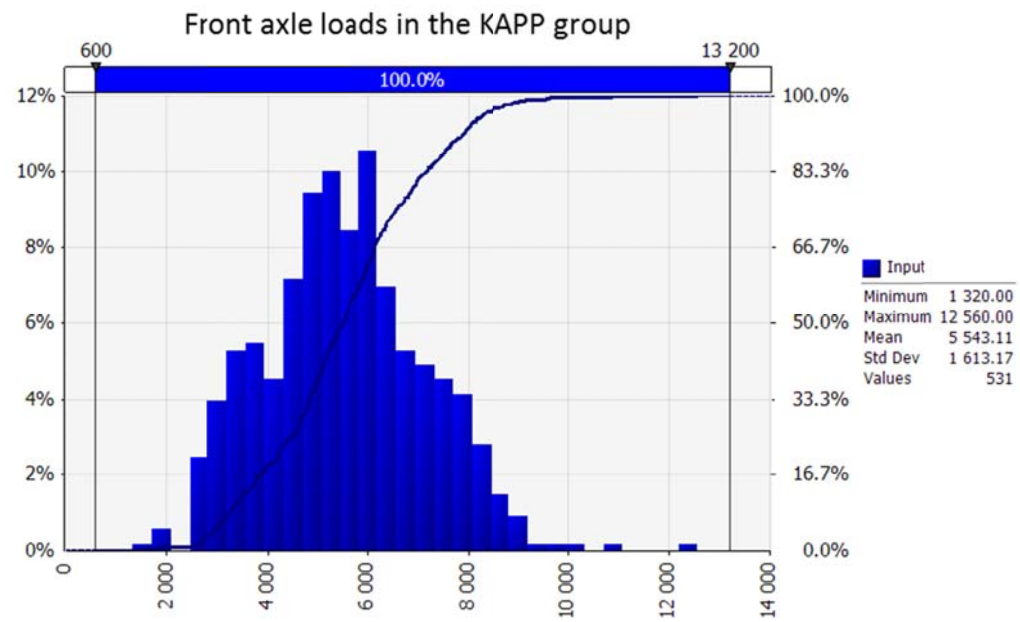


Figure 78. KAPP front axle loads.

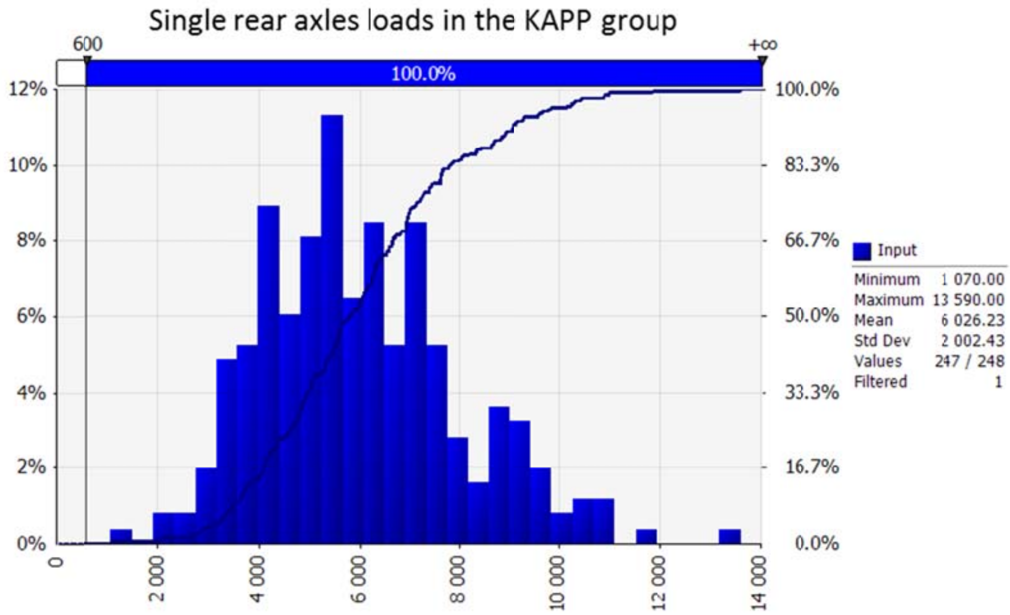


Figure 79. KAPP rear axle loads.

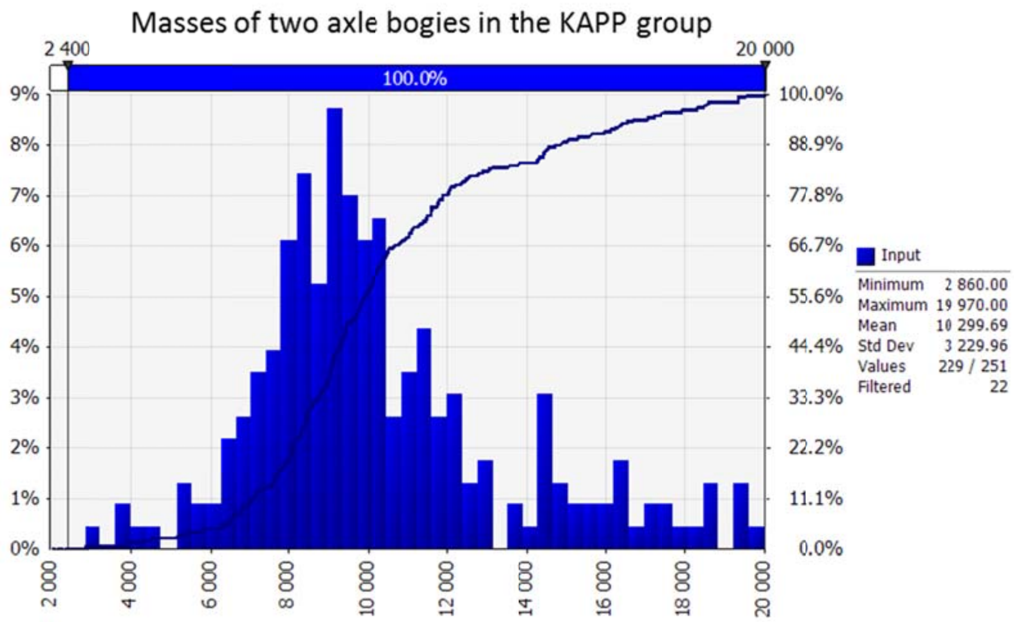


Figure 80. KAPP two axle bogie masses.

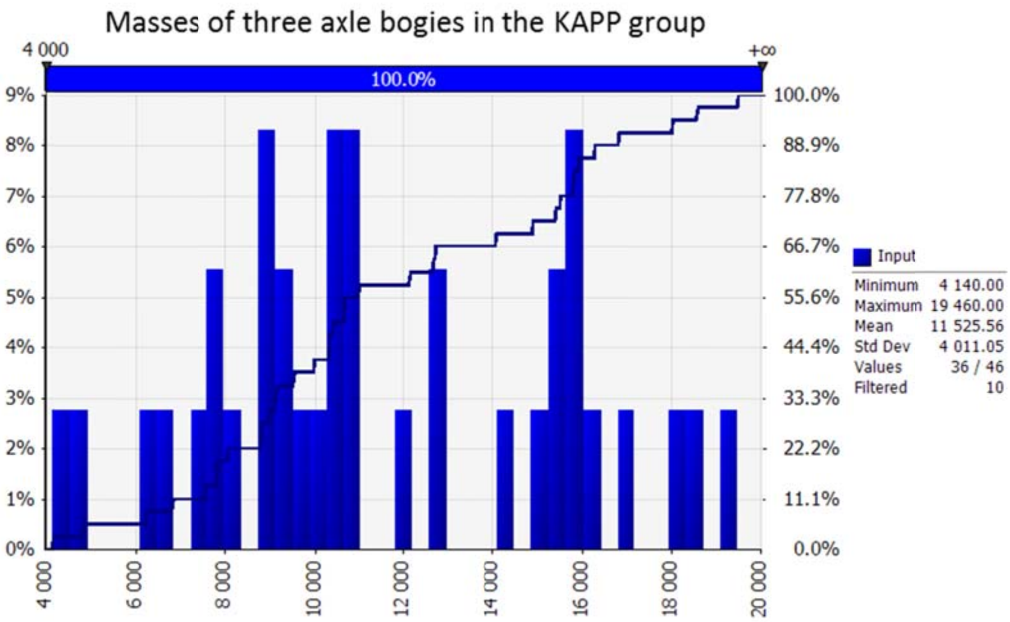


Figure 81. *KAPP three axle bogie masses.*

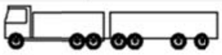
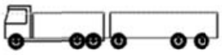
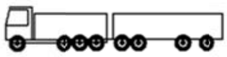
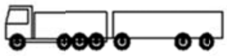
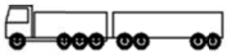
3.3 Trucks with trailers

3.3.1 Axle distances and average axle loads

Table 27. *Axle distances (m) of full-trailer combinations.*

Type	KAVP	Fraction	1 axel	2 axels	3 axels	4 axels	5 axels	6 axels	7 axels
	2+211	0,0 %	-	-	-	-	-	-	-
	2+111	0,0 %	-	-	-	-	-	-	-
	2+22	40,4 %	4,6	1,3	4,9	1,4	5,7	1,7	-
	2+12	2,9 %	4,7	1,4	5,3	5,2	2,1	-	-
	3+211	0,0 %	-	-	-	-	-	-	-
	3+111	0,0 %	-	-	-	-	-	-	-
	3+22	4,2 %	3,9	1,3	1,3	4,6	1,3	5	1,6
	3+12	5,3 %	3,4	1,5	1,3	4,7	4,2	1,9	-
	2+23	37,2 %	4,8	1,3	5,0	1,3	5,8	1,3	1,3
		89,9 %							

Table 28. Average axle loads and bogey masses (kg).

Type	KAVP	Fraction	Front Axel	axel 2	axel 3	axel 4	axel 5	axel 6	axel 7	axel 8
	2+211	0,0 %	-	-	-	-	-	-	-	-
	2+111	0,0 %	-	-	-	-	-	-	-	-
	2+22	40,4 %	6738	9340	7091	5249	5482	6239	6116	-
			15 %	20 %	15 %	11 %	12 %	13 %	13 %	
	2+12	2,9 %	6523	8808	5781	5650	4539	4748	-	-
			18 %	24 %	16 %	16 %	13 %	13 %		
	3+211	0,0 %	-	-	-	-	-	-	-	-
	3+111	0,0 %	-	-	-	-	-	-	-	-
	3+22	4,2 %	7143	7206	8097	7171	5806	6073	6777	6580
			13 %	13 %	15 %	13 %	11 %	11 %	12 %	12 %
	3+12	5,3 %	6286	6593	8693	7710	6474	5953	5947	-
			13 %	14 %	18 %	16 %	14 %	12 %	12 %	
	2+23	37,2 %	6615	9175	6338	4993	5132	4597	4657	4577
			14 %	20 %	14 %	11 %	11 %	10 %	10 %	10 %
		89,9 %								

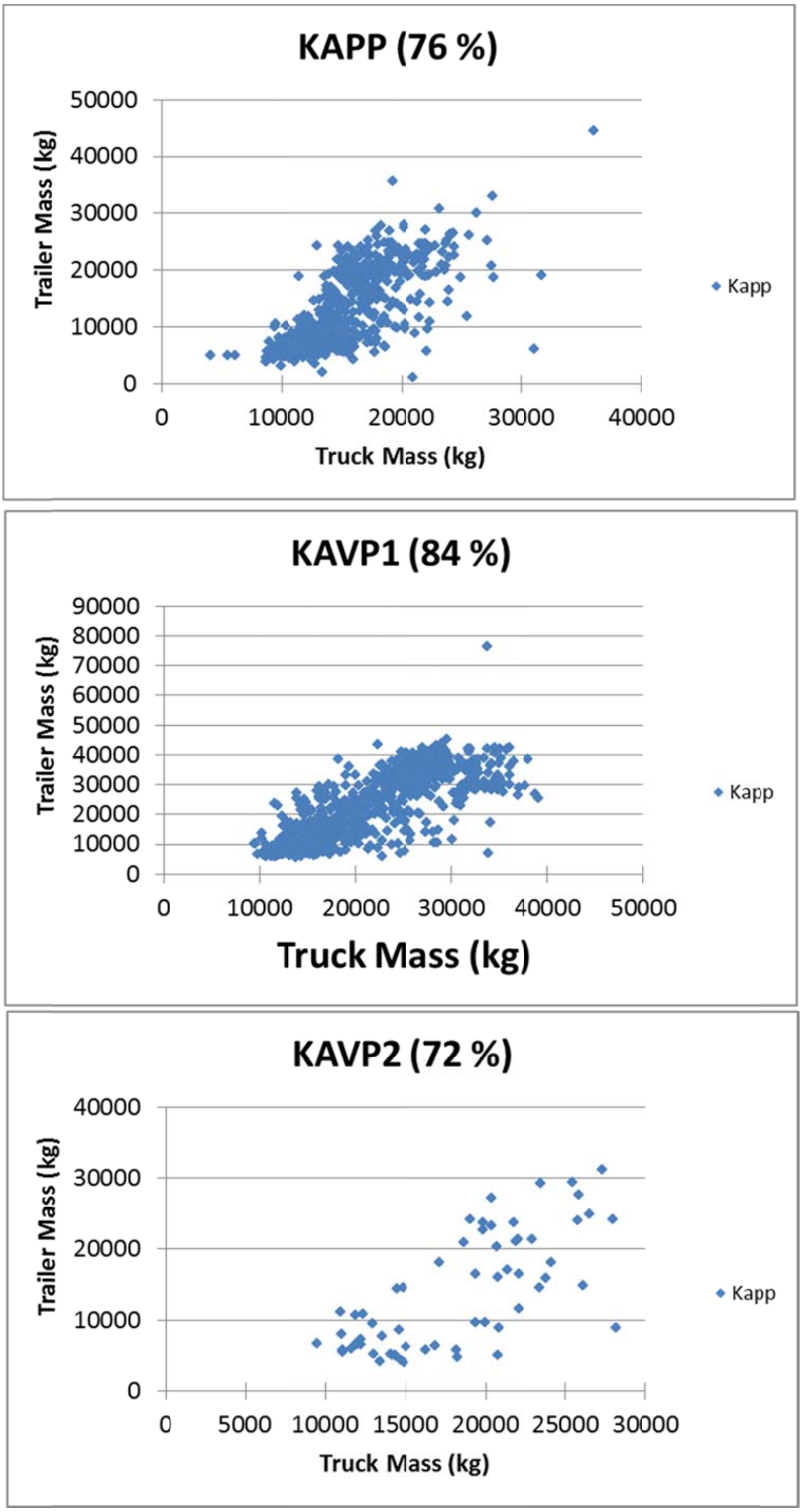


Figure 82. The correlation between truck and trailer masses.

4 Quality assurance of the results

4.1 Quality assurance in general

The goal has been to validate the measurement results by inspecting the data through random sampling and logic analysis.

Approximately 10 % of the entire measurement data was inspected by random sampling. The sampling involved confirming that the correct photo was paired with the correct weighing data and that the number of axles and their configuration (lifted/down) corresponded with the photograph of the vehicle. If errors were found they were corrected and the results were updated accordingly. Photos not paired with their corresponding vehicles are an example of an observed error. After the correction process was complete, correct photos were paired with their corresponding vehicle data, in the results.

The next step was the logic analysis of data where the aim was to find erroneous results from the data. One crucial element was that a registered axle did *not* have a weight of zero in the data. If such results were found, the weighing results were corrected when possible. Where correction was not possible, the erroneous results were removed from the data. Out of the 2014 measurement results, 24 vehicles were removed. The most common reason for erroneous results was high speed of the measured vehicle while crossing the scale. On a few occasions the vehicle even fell off the scale while crossing it, which resulted in the rear axles not being measured.

After the raw data was validated and the proper corrections were made, the data was processed.

4.2 Errors discovered during data processing

Errors were discovered during processing which were already revealed during the logic analysis. In some instances, an axle was recorded as belonging to a trailer when it in fact should have been a part of the truck. This was usually discovered when axle configurations appeared unusual or uncommon. Vehicles, where such discoveries were made, were inspected through photographs to determine the correct axle configurations and to make the appropriate corrections. This also had an effect on the formation of bogie groups and therefore these were corrected as well.

In some instances an axle that was down was marked having a weight of zero. These axles were marked as being lifted.

4.3 The repeatability of the measurement results

The repeatability of the axle load weighing equipment was tested by weighing a select few vehicles four times in total and by inspecting the repeatability through the CageR&R method. The error margin for repeatability was found to be 3 %, which can be considered to be very good.

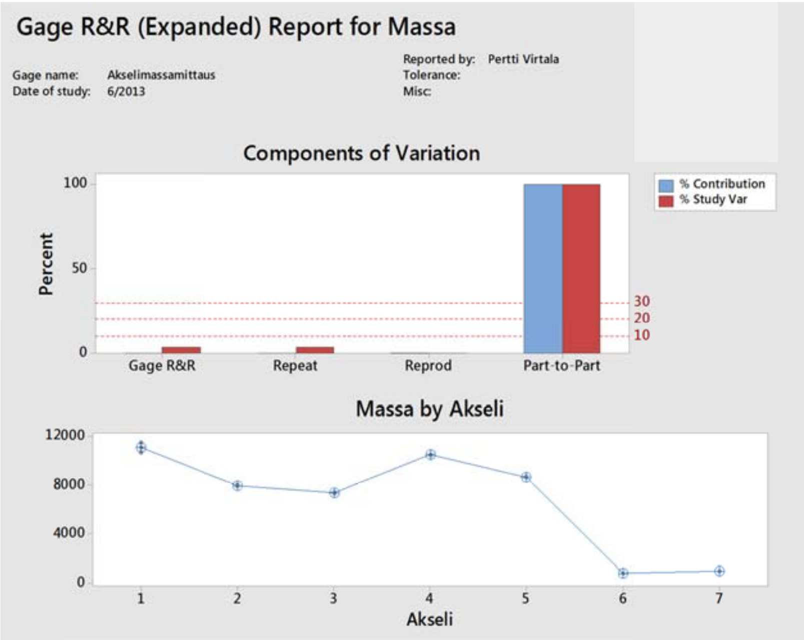


Figure 83. CageR&R analysis.

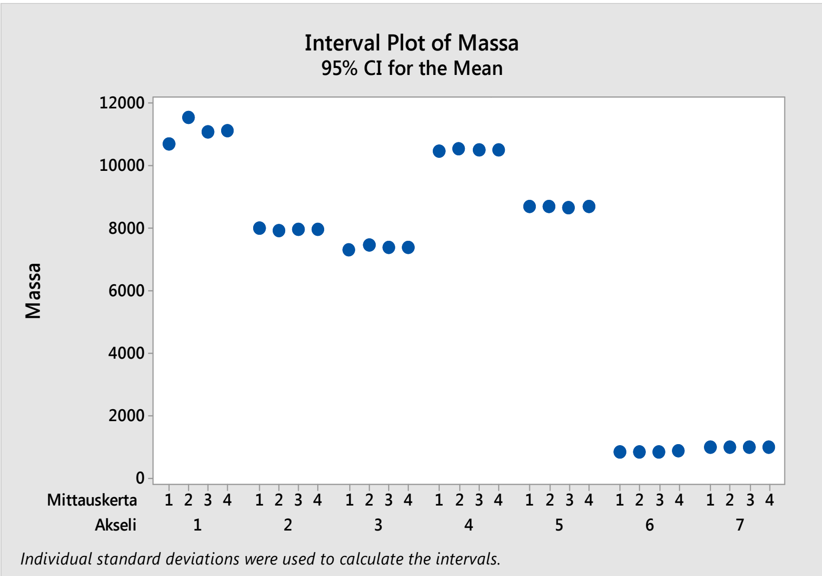


Figure 84. Fluctuations in weighing results during repeated measurements.

Sources

1. Pihlajamäki Jari: Liikennerasituksen laskeminen. VTT Rakennus- ja yhdyskuntatekniikka. TPPT-menetelmäkuvaus. Tien pohja- ja päällysrakenteet – tutkimusohjelma 1994-2001. Espoo 2001.
2. Räty P., Pursiainen J. Akselimassatutkimus1998. TIEL publications. Helsinki 1999. 275 s.
3. Kulauzovic B., Znidaric A., Brozovic R. Cestel D - Reports and results. Ljubjana 2012

Precise location of the measurement points by measurement areas.

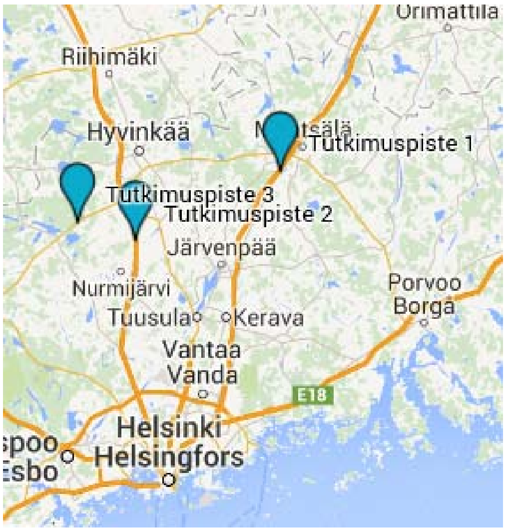


Figure 1. Axle load study measurement points in Uusimaa.

Figure 2. Axle load study measurement points in Southwest ern Finland.

Figure 87. Axle load study measurement points in Southeastern Finland.

Figure 88. *Axle load study measurement points in Central Finland.*

Figure 89. *Axle load study measurement points in Northern Ostrobothnia.*

Figure 90. *Axle load study final measurement point in Summa, Hamina.*

MITTAUSESITE – MÄTBROSCHYR – MEASUREMENTS BROCHURE

Hyvä kuljettaja,

Liikennevirasto tekee tutkimusta ajoneuvojen akselipainoista. Olethan ystävällinen ja osallistut tutkimukseen, joka pitää sisällään lyhyen haastattelun ja akselipainojen mittauksen. Arvio tutkimuksen kestosta on noin 5 minuuttia. **Tutkimustulokset ovat luottamuksellisia.**

Tutkimustuloksia käytetään tie- ja katuverkon sekä siltojen kunnossapitotarpeen selvittämiseksi. Osallistumisesi on tärkeää mahdollisimman kattavan tutkimustuloksen saamiseksi.

Vaaka ylitetään ajamalla hitaasti, tasaista vauhtia ja pysähtymättä koko matkan.

Kiitoksia ja turvallista matkaa!

Bästa förare,

Trafikverket genomför en undersökning om fordonens axeltryck. Vi ber er att delta i undersökningen, som innehåller en kort intervju och mätning av axeltrycket. Undersökningen beräknas ta ungefär 5 minuter. **Resultaten är konfidentiella.**

Resultaten från undersökningen används för att utreda behovet av underhåll för väg- och gatunätet samt broar. Ert deltagande är viktigt för att erhålla ett så heltäckande resultat från undersökningen som möjligt.

Kör över vågen sakta, med konstant fart och utan att stanna.

Tack och ha en säker resa!

Dear driver,

Finnish Road Administration is performing a research concerning vehicle axle load. You are kindly requested to participate in this research, which includes a short interview and axle load measurement. The estimated duration of your participation is about 5 minutes. **The research results are confidential.**

The research results will be used to determine the maintenance needs for the road network and bridges. Your participation is important in order to receive as comprehensible and reliable results as possible.

Drive over the scale slowly, steadily and without stopping at all.

Thank you and have a safe trip!

Lugupeetud autojuht,

Maanteeamet (Liikennevirasto) viib läbi uuringut mootorsõidukite teljekoormustest. Loodame, et leiate aega osalemaks uuringus, mis sisaldab lühikest intervjuud ja teljekoormuste mõõtmist. Uuringuks kulub umbes 5 minutit. **Tulemused on konfidentsiaalsed.**

Tulemusi kasutatakse teede, tänavate ja sildade remondivajaduste selgitamiseks. Teie osalemine on oluline tõepärasemate tulemuste saamiseks.

Kaalust tuleb üle sõita aeglaselt, tasase kiirusega ning peatumata.

Aitäh ja head reisi!

Уважаемый водитель,

Управление дорожного движения Финляндии проводит исследование осевой нагрузки транспортных средств. Пожалуйста, примите участие в исследовании, которое включает в себя короткое собеседование и измерение осевой нагрузки Вашего автомобиля. Исследование займет примерно 5 минут.

Результаты исследования являются конфиденциальными и используются для определения необходимых мероприятий по содержанию дорог, улиц и мостов в надлежащем порядке. Ваше участие в исследовании является важным с точки зрения получения всеобъемлющих и достоверных результатов.

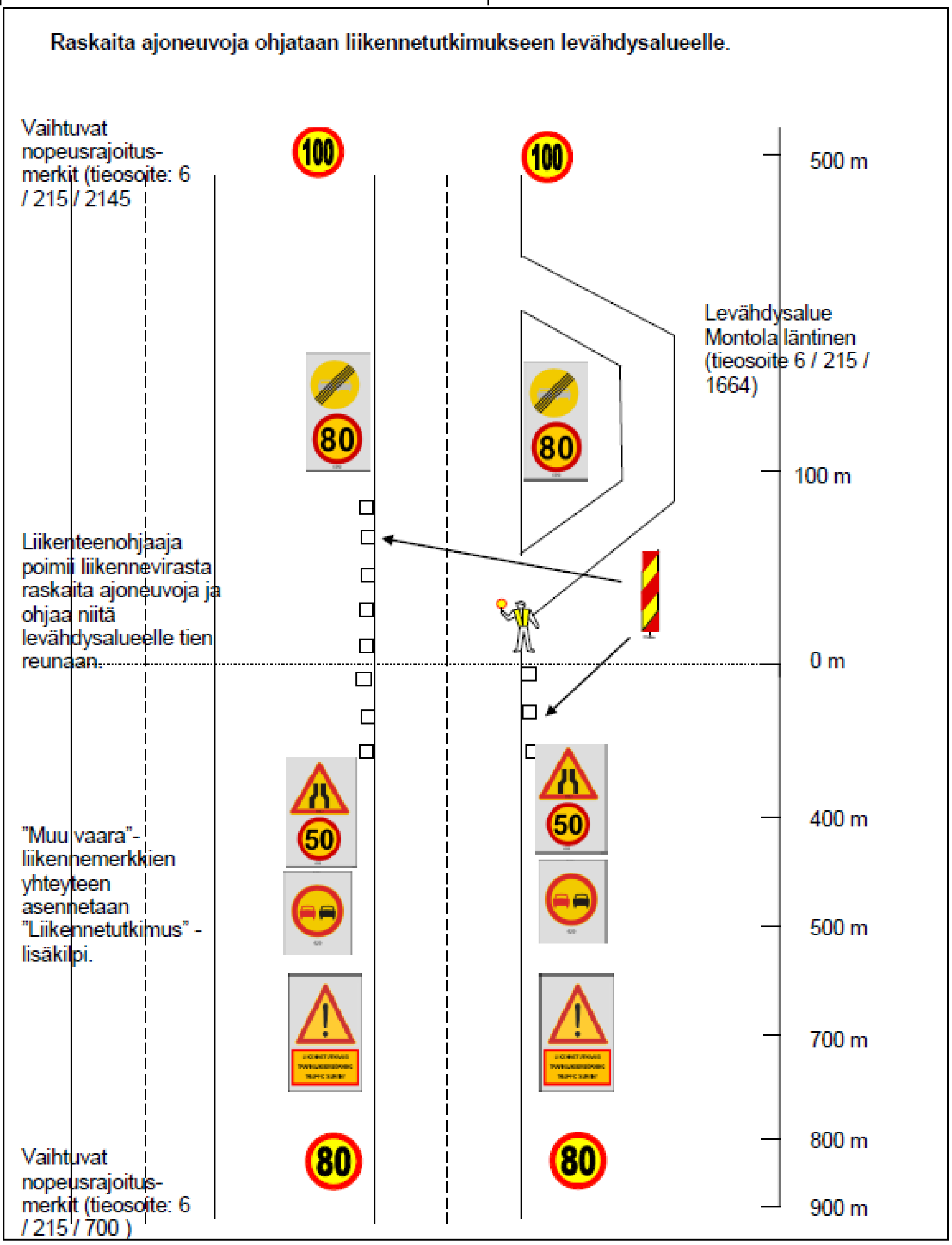
Проезд через измерительные весы необходимо производить медленно с постоянной скоростью, без остановок.

Спасибо и безопасного пути!

Traffic control plan

LIIKENTEENOHJAUSSUUNNITELMA

Projekti, urakkaosa	
Liikennejärjestelyt akselimassatutkimuksien ajaksi VT6:lle, suunta 1	
Laatija Janne Toikka	Pvm. 15.5.2014
Hyväksyjä	Pvm.



Comparing the formulas used for calculating the load equivalent values

The reported load equivalent values in the axle load study were calculated with the following formula:

$$ESAL = \sum_{i=1}^{n} a_i * \left(\frac{P_i}{P_n}\right)^4$$

, where:

the axle reference weight P_N is determined according to the number of axles, tyre types and suspension types. The possible values of P_N are presented in table 16.

An alternate formula has been picked out from the BWIM manufacturer's Cestel's handbook "D – Reports and results." The formula has been used in the processing of the data acquired by Trafikia in their measurements commissioned by the Finnish Transport Agency.

$$ESAL = \sum_{i=1}^{n} 10^{-4} * ft * fa * (P_i)^4$$

, where:

fa is a factor dependent on the number of axles in the bogies. The formula can also be factored into the following form:

$$ESAL = \sum_{i=1}^{n} ft * \left(\frac{P_i}{P_n}\right)^4$$

, where:

the reference weight P_N is either 10, 18, or 24 tons for 1, 2, or 3 axle bogies respectively.

The ESAL calculation for axles and bogies has been shown for a select number of actual vehicles from the study in the tables below. Due to different reference weights and the so-called "power of 4" rule there are notable differences in the ESAL value between the different methods. In some instances, however, the ESAL value for an individual axle may be identical with both methods.

The first example represents a typical load in a KAPP vehicle group and the final example represents a heavy load in the KAVP1 vehicle group. A picture below the table shows the vehicle for which the values are being calculated.

Appendix 4 / 2 (2)

Example 1.
Axle load Study vehicle ID 6.

Akseli	Punnitustulos	Jousitus	Rengastus	Pi Destia	Pn Destia	Pi Trafikia	Pn Trafikia	ESAL Destia	ESAL Trafikia
1	7310	Muu	Yksittäispyörä	7310	7700	7310	10000	0.812	0.286
2	9190	Ilmajousi	Paripyörä	9190	10000	9190	10000	0.713	0.713
3	5440	Ilmajousi	Supersingle						
4	5360	Ilmajousi	Supersingle	16220	23500	16220	24000	0.227	0.209
5	5420	Ilmajousi	Supersingle						
Yhteensä								1.753	1.207

Example 2.
Axle load Study vehicle ID 1948.

Akseli	Punnitustulos	Jousitus	Rengastus	Pi Destia	Pn Destia	Pi Trafikia	Pn Trafikia	ESAL Destia	ESAL Trafikia
1	7090	Muu	Yksittäispyörä	7090	7700	7090	10000	0.812	0.253
2	7040	Muu	Yksittäispyörä						
3	10420	Muu	Paripyörä	27560	24000	27560	24000	1.739	1.739
4	10100	Muu	Paripyörä						
5	11000	Muu	Supersingle	11000	8700	11000	10000	2.556	1.464
6	8360	Muu	Supersingle	21130	16406	21130	18000	2.752	1.899
7	12770	Muu	Supersingle						
Yhteensä								7.858	5.355

Finnish Transport Agency

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